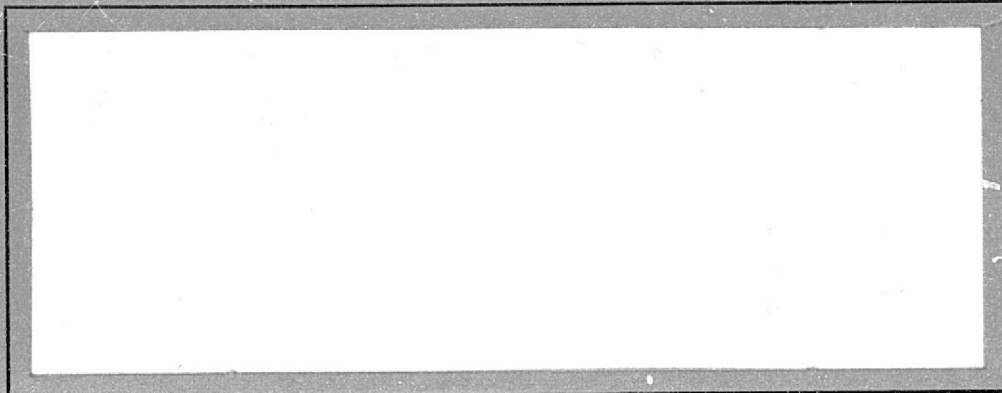


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COSTA MESA

CALIFORNIA

(NASA-CR-150908) OPTICAL EFFECTS MODULE
Final Report (Advanced Kinetics, Inc., Costa
Mesa, Calif.) 80 p HC A05/MF A01 CSCL 20F

N79-16664

Unclas

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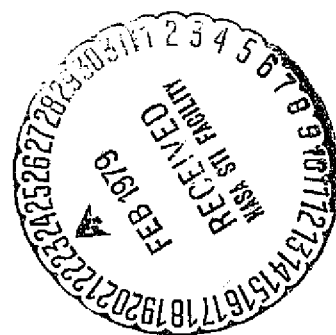


ADVANCED KINETICS, INC.

OPTICAL EFFECTS MODULE

Contract NAS8-32090

FINAL TECHNICAL REPORT



Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
MARSHALL SPACE FLIGHT CENTER, ALABAMA 35812

October 1, 1978

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GENERAL DESCRIPTION OF OPTICAL EFFECTS MODULE

A) BASIC FUNCTIONS

The basic function of the Optical Effects Module is to determine the possible degradation of optical samples exposed to the effluent gases and particulate matter emanating from the payload of the Space Transportation System during orbital operations.

The method adopted consists in measuring two optical parameters for five samples exposed to this environment, namely transmittance and diffuse reflectance. Any changes detected in these parameters as a function of time during the mission are then attributable to surface contamination or to increased material absorption.

These basic functions are attained in the Optical Effects Module by virtue of the following subsystems:

- Module Enclosure
- Light Source with Collimator and Modulator
- Sample Wheel with Holders and Rotary Drive
- Photomultipliers for Radiation Detection
- Processing and Sequencing Electronic Circuitry
- Power Conditioning Interfaces

The functions of these subsystems are reviewed here and specified in more detail in this technical presentation.

B) MODULE ENCLOSURE

The Module Enclosure provides the housing for the optical instrumentation and for the processing electronics. Furthermore, the outer surfaces of this enclosure are

designed to stabilize the thermal excursions of the package and to reject heat into the coupling rail of the IECM.

The baseplate is 6 mm thick aluminum plate 6061-T6 with provisions for bolting the same by means of six 1/4-20 stainless steel screws to the IECM rail. This baseplate is $28 \times 28 \text{ cm}^2$ ($11 \times 11 \text{ in}^2$) and it provides the framework for attachment of all the other sideplates and rigidizing structures. This baseplate is ground to a finish of 60 μ inch to insure minimization of the temperature gradient at the rail interface.

Two " L " shaped aluminum bars are bolted along the length of the baseplate providing a rigidizing support. Each leg of the " L " is 6 mm thick and 32 mm wide, the rails are 23 cm long (11 in).

The optical plate of the OEM separates the package into two volumes which are approximately equal. The top compartment houses all the optical elements, the source and a portion of the sample wheel. The other compartment contains the electronic subsystems, power supplies and the stepping motor for driving the sample wheel. This optical plate is secured to the base rails by means of six 8-32 stainless steel screws. The optical plate is 6 mm thick aluminum 6061-T6.

The optical plate serves a further purpose in that it provides structural rigidity for the remainder of the package in a plane orthogonal to the baseplate. Additional " L " sections are attached to this plate to provide lateral ribbing.

In view of the weight restrictions, all the covering surfaces are aluminum plate 6061-T6 1.6 mm (0.062 in) thick. All the plates are securely fastened together with 6-32 and 8-32 stainless steel screws provided with lockwashers.

The external surfaces of the plates are treated to achieve thermal stability of the package. The selected finish for various surfaces is described in the section on Thermal Analysis.

As previously indicated, the electronic and optical compartments are separated by the optical plate, but not hermetically. However, careful control is being exerted on the materials to be used to minimize outgassing effects. Outgassing from the stepping motor and power supply inverter has already been examined at the MSFC facilities by means of quadrupole mass spectrometer and found to be within completely acceptable limits.

C) LIGHT SOURCE AND MODULATOR

The illumination of the sample is provided by a low pressure, cold cathode mercury vapor discharge lamp. A double bore tubing of fused quartz contains the active plasma medium and limits transmission of radiation to wavelengths longer than $1800 \text{ \AA}$. The principal radiance of the light source is due to the Hg I line at $2536.52 \text{ \AA}$. The bremsstrahlung background and other lines contribute to only 3% of the total irradiance.

The lamp selected for this operation is the Hamamatsu Model L937-001 with a lighted region of 25 mm length and a tube diameter of about 6 mm.

The experiments conducted during the Preliminary Design Phase (PDP) have indicated that the lifetime of this source is severely reduced if operated under DC conditions. Since the breakdown voltage of this lamp ranges into the region of 1350 V for ambient temperatures from 0°C to 25°C , we require an AC power supply featuring a crest voltage to reliably ionize the lamp.

The AC power supply drives the lamp at 1.6 kHz. This power supply has been tested with good results and is suitable for space environment.

Modulation of the beam will be provided by a Bulova tuning fork chopper. The frequency of this device is around 200 Hz, so that approximately 8 lamp current modulation cycles will be contained in one chopper cycle envelope.

The tuning chopper provides a synchronous signal for lock-in amplification. An isolation transformer is used to decouple the +29 VDC ground from the signal ground as required by the IECM guidelines.

D) SAMPLE WHEEL WITH HOLDERS AND ROTARY DRIVE

The sample holder subsystem features a carousel configuration with six sample positions. The wheel of the carousel is an aluminum disc of 230 mm (9 inch) diameter and 3 mm thickness fastened to a spindle which is supported on three axial bearings. The sample wheel is driven at 90° to the axial drive shaft by means of a worm gear assembly.

A stepping motor is securely fastened by means of a 90° bracket to the underside of the optical plate. This motor provides positive and accurate displacement of the wheel. The worm gear is adopted to generate a natural detent to prevent slippage of the sample wheel during the power-off cycle. The stepping motor features a stepping increment of 7.5° and it requires 0.5 sec to index to each subsequent sample position in 100 drive steps. This includes the ratio of the worm gear which is 12.5:1.

A photodetector-LED combination will be used to generate location information and for interfacing the processing electronics.

The five samples will be installed on sample holders spaced 60° apart. One empty sample holder will be used for normalizing purposes.

E) PHOTOMULTIPLIER RADIATION DETECTORS

The radiation transmitted through the samples or diffusely scattered will be detected by two photomultipliers.

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The photomultiplier tube (PMT) for the transmission measurement will be operated at approximately -1000 VDC at a current amplification factor of approximately 10^3 .

The PMT for the scattered intensity will be operated at -1500 VDC at a current amplification factor of $2 \cdot 10^5$.

The PMT's are the EMR Model 510F-09-13. One power supply is used to feed both PMT's.

The transmitted and scattered radiation signals are modulated at a frequency of 1.6 kHz.

F) PROCESSING ELECTRONICS AND ELECTRICAL INTERFACES

The electronic subsystems comprises all the circuitry necessary to drive the sampling wheel in a predetermined time cycle, sense positions and stop at each sample for the measurements and complete the sequence. The signals are processed by synchronous lock-in amplification and the rectified rms levels are made available for recording.

All the electrical power required for these functions and also for energizing the UV lamp and the radiation modulator are derived from the 28 VDC line by solid state inverter packages.

These components are properly located below the optical plate to which they are fastened for the required heat-sinking.

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RADIATIVE AND THERMAL ENVIRONMENT

A) DESCRIPTIVE PARAMETERS

A primary objective in the preparation of the external surfaces of the OEM is to insure temperature stability of the package. This aim is pursued not only to safeguard the integrity of the components, but, more immediately, to achieve the accuracy required for the sample transmission and scattering measurements. Effects induced by temperature drifts in the electronic components are examined in another section of this review.

The temperature stability of the package is predicated by the radiative and thermal environment which is analyzed in this section. The following parameters are of basic importance in determining the time profile of the temperature of the OEM:

1) Internal Dissipation

The time cycle of the OEM is assumed to be characterized by a duty factor of 0.15, approximately. Some components must be energized continuously, whereas other subsystems are operated only during the on-time of the cycle. This results in an average internal dissipation of 25 - 26 W. If this dissipation is related to the OEM surface available for radiative heat exchange ($A = 355 \text{ cm}^2$, as defined by the radiative mask), we obtain a power density of $5.6 \cdot 10^{-2} \text{ W/cm}^2$. Assuming a ratio of solar absorptance to emissivity $\alpha/\epsilon = 1$, we can compute an equilibrium temperature of the package of approximately 75°C.

This figure is obtained under complete decoupling of the OEM from the thermal rail.

2) Thermal Power from Insolation

For the normalized altitude of several missions ($\equiv h/R_e = 220 \text{ km}/6373 \text{ km} = 0.035$), the percentage of sunlight per orbit remains approximately constant for a range

of orbital attitudes (angle β between ecliptic and spacecraft orbit). Thus, a 60%/40% apportionment between sunlight and darkness applies to a number of situations. This factor is used to weigh the absorbed solar flux.

The thermal power due to insolation is computed to 47 W, if the previously indicated surface of 355 cm^2 is exposed to the solar flux. The solar absorptance α determines the fraction of this thermal power which is actually absorbed by the OEM system.

The influx due to terrestrial emission (2 W) and albedo (1 W) represent rather minor components and these can be incorporated during the computations in the time average of the insolation.

3) Power Emitted by Reradiation

The power reradiated by the OEM into outer space is readily computed under assumption of a surface emissivity $\epsilon = 0.85$ and a package temperature of 300°K . The radiated power is about 14 W.

4) Heat Exchange under Blanket

We assume that under the blanket the different packages will be in a state of quasi-equilibrium. The argument for this is simply that the thermal rail will be short-circuiting the packages. The residual differences will be due to the thermal contact discontinuity. For the OEM, we have specified an acceptable thermal contact conductance which will lead to a step transition of 1.46°C for a maximum flow of 65 W.

If a similar transition exists between adjacent packages, the temperature difference cannot exceed $3^\circ - 5^\circ\text{C}$. Under these conditions and for $\epsilon = 0.2$, we expect the radiative exchange to be less than $1 \text{ W} / 1000 \text{ cm}^2$ of interacting surface.

Thus, the dominant process under the blanket will be thermal equilibration by conduction to the rail with a minor radiative exchange superimposed.

5) Leakage to Surrounding Spacecraft

The leakage by conduction and radiation to the spacecraft structure cannot be readily computed because of unknown geometrical factors. However, we can simplify the problem by assuming conductive decoupling and radiative exchange to a surrounding blanket of idealized spherical structure.

The total OEM surface, excluding the frontal surface which is in radiative exchange with space, amounts to 5130 cm^2 . This includes the bottom plate in contact with the thermal rail. If the surfaces are clean aluminum, the emissivity $\epsilon = 0.04$. The emissivity of the surrounding blanket will be $\epsilon_b = 0.03$. For the temperature of the OEM we assume 320°K and for that of the blanket 250°K . The radiative leakage will be 7 W.

B) TYPICAL TEMPERATURE CYCLES

1) OEM Decoupled from Thermal Rail

These parameters provide the input for calculations which are carried out under different approximations. The first model of interest is one in which the OEM is fully decoupled from the thermal rail. We have programmed the descriptive equations of this system and we can input the following variables: solar absorptance α , emissivity of OEM front surface ϵ , initial temperature of OEM T_0 , sunlight/darkness cycle which is slightly β -dependent. We can then follow the temperature rise of the package under different assumptions for these variables and for complete decoupling from the thermal rail. Attached to this section of the review are print-outs for a few situations of interest.

We have first examined the case for which $\alpha/\epsilon = 1$. This situation is met typically for $\alpha = 0.9$ and $\epsilon = 0.35$ which yields $\alpha/\epsilon = 1.06$. In this case, we should have a black anodized front surface with a coarse sandblast finish.

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The second case covers another extreme with $\alpha/\epsilon = 0.25/0.9 = 0.28$. This finish is achieved by application of a suitable paint (e.g. Cadillac white, or similar).

The first case has been followed for 20 orbits, corresponding approximately to the 30 hours of the OFT-1 mission. We notice that the temperature rise/orbit is about 2.6°C and that this increment tapers off to about 2°C towards the end of the 20th orbit. This case is characterized by $\alpha/\epsilon = 0.9/0.85 = 1.06$ and the resultant end temperature is $74^{\circ}\text{C} = 347^{\circ}\text{K}$.

The second case has been followed for a similar period and the temperature increase is only 1°C/orbit , resulting in a final temperature of $44^{\circ}\text{C} = 317^{\circ}\text{K}$. Here, the $\alpha/\epsilon = 0.25/0.90 = 0.28$.

The second approach would be more suitable to the thermal environment of the OEM, since it would minimize temperature fluctuations. However, the serious drawback is that a painted surface would be required in the immediate proximity of the samples. In spite of the tested durability of selected paints, there is no way of avoiding deterioration and flaking under the action of external UV radiation. Hence, these particles would immediately deposit on the closest dielectric surface under the action of the accumulated charge. Thus, we foresee deposition on the exposed samples.

The next step is to test the same configurations under coupling to the thermal rail to determine if the temperature excursion of the first case can be suitably limited.

2) OEM Coupled to Thermal Rail

The previous computations have indicated that the OEM could be maintained in operation only with $\alpha/\epsilon \leq 0.3$, if it were decoupled from the rail.

The next step is to introduce the mass of the added rail contributing to the thermal inertia of the system. Thus, to the OEM mass of approximately 12,000 gm, we add the

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rail mass of 30,390 gm for a total mass of 42,390 gm. To minimize the complexity of the treatment, we ignore the coupling to the other packages of the IECM.

The effect of this coupling results in a predictable decrease of the OEM temperature for each orbit. The two cases for $\alpha/\epsilon = 1.06$ and 0.28 are indicated by print-outs which are enclosed.

For the case of $\alpha/\epsilon = 1.06$, we notice that the temperature rises to $331^\circ\text{K} = 58^\circ\text{C}$ after the 20th orbit, as opposed to $351^\circ\text{K} = 78^\circ\text{C}$ for the same case but without coupling to the rail.

For the case of $\alpha/\epsilon = 0.28$, the final temperature is about $315^\circ\text{K} = 42^\circ\text{C}$, as contrasted to $317^\circ\text{K} = 44^\circ\text{C}$ for the decoupled case.

We have analyzed several other cases corresponding to the various surfaces and finishes. A summary of all the results can be presented as follows:

			α/ϵ	T_{20}
Aluminum 6061-T6, sandblasted with 120 grit size	$\alpha = 0.60$	$\epsilon = 0.41$	1.46	332°K
Aluminum 6061-T6, polished and degreased	$\alpha = 0.35$	$\epsilon = 0.04$	8.75	332°K
Aluminum 6061-T6, hard coat anodized, 25 μm thickness	$\alpha = 0.92$	$\epsilon = 0.85$	1.08	331°K
Aluminum 6061-T6, gold-plated over intermediate Ni layer	$\alpha = 0.30$	$\epsilon = 0.03$	10	331°K
Painted aluminum surface Cadillac white	$\alpha = 0.25$	$\epsilon = 0.90$	0.28	315°K

All of these calculations are carried out with coupling to the rail, but without loading the thermal rail with other packages. In the last column, we have indicated the temperatures which the OEM attains after the 20th orbit.

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We have attempted also to describe the coupling of the thermal rail to the OEM by means of an additional conductivity term. This formulation takes into account a temperature step due to the transition between the package and the rail. The alternate description of the coupling yields temperatures which are higher by about 5°K, as compared to the case where the coupling is described just by the additional mass of the rail. A print-out of these alternate results for the specific case of $\alpha/\epsilon = 0.9/0.85$ is attached.

We have also treated the case of "cold orbits" where the insolation term drops to zero because of the attitude of the spacecraft with respect to the orbital plane. For the sake of convenience, we have made $\alpha = 0$ to eliminate this contribution. The print-outs indicate the following temperatures at the end of the 20th orbit.

		T_{20}
Aluminum	$\epsilon = 0.85$	309.6°K
	$\epsilon = 0.41$	316.5°K
	$\epsilon = 0.04$	322.8°K
	$\epsilon = 0.03$	323.0°K

In this case, the low thermal emissivity of the surface is the proper approach for maintaining moderate temperatures of the package.

C) THERMAL ENVIRONMENT CONTROLS FOR OEM

These analytical results provide useful guidelines to be adopted in the construction of the OEM package and interfaces. These guidelines will be discussed now in more detail.

1) Specifications for Thermal Rail Interface

The interface between the bottom plate of the OEM and the thermal rail provided in the IECM is of primary importance to the thermal stability of the instrument.

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The quality of the interface and the contact pressure applied determine the thermal gradient which is developed. This thermal step induces in turn a higher operating temperature in the instrument.

We would like to maintain this gradient on the order of 1°C . We can therefore compute the thermal contact conductance h_c which is acceptable for this interface

$$h_c = Q / A \cdot \Delta T$$

Where Q is the thermal flow in W , A is the contact area in cm^2 and ΔT is the temperature step in $^{\circ}\text{C}$. The contact area of the OEM bottom plate is 780 cm^2 and $Q \approx 45 \text{ W}$ during the power cycle. Hence,

$$h_c = 5.7 \cdot 10^{-2} \text{ W} / ^{\circ}\text{C} \cdot \text{cm}^2$$

We have now to determine which contact pressure and surface finish is required to achieve this thermal conductance.

Practical parameters are typically a surface finish of better than $60 \mu\text{inch}$ and a pressure of less than 2 atm (25 psi). This pressure entails a total force of 1380 kg , or about 230 kg for each of the six bolts which fasten the OEM to the thermal rail. This stress is acceptable since it corresponds to about $1/7$ of the elastic limit for the $1/4\text{-}20$ stainless steel bolts foreseen for use.

We require therefore a finish of the contacting plates of better than $60 \mu\text{inch}$ to maintain the desired thermal impedance.

These specifications are suggested for adoption and the OEM plate will be prepared to satisfy this finish with a flatness of $25 \mu\text{m}$ over the total extension of the plate in both directions.

2) Specifications for Surfaces Exposed through Blanket Opening

The choice of the surface finish of the OEM is dictated mainly by the requirement of minimizing spacecraft energy. We have seen that a high emissivity leads to marginal

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temperature increments during cold orbits. This in turn may necessitate heat input from the thermal rail. This method of increasing the temperature of the package is clearly inefficient. Every package should be nearly thermally stable on its own account. Temperature excesses should be absorbed by the thermal rail and then disposed through the large spacecraft area into space.

Hence, we have selected the gold-plating for the frontal area of the OEM which is exposed to insolation. We deliberately avoid the use of paints in close proximity to the samples because of the possibility of deterioration under the influence of UV radiation and subsequent deposition on the dielectric surfaces. The gold-plated surface maintains acceptable temperatures in the case of cold orbits. This finish also yields relatively small temperature excursions during hot orbits. The following table summarizes the reasons for this decision:

<u>Emissivity of Surface</u>	<u>T (Cold Orbit)</u>	<u>T (Hot Orbit)</u>	<u>ΔT</u>
$\epsilon = 0.85$	310°K	331°K	21°K
$\epsilon = 0.41$	316°K	332°K	16°K
$\epsilon = 0.04$	323°K	332°K	9°K
$\epsilon = 0.03$	323°K	331°K	8°K

We obtain therefore not only a minimization of the energy input from the thermal rail, but also the best conditions in terms of temperature stability of the package. The gold layer will be 0.00005 inch (= 1.3 μ m) thick and it will be applied on an intermediate nickel layer on top of the aluminum surface. For the sake of avoiding scattering inside the chamber, the sample holders will be black anodized and the sample wheel will be treated similarly.

All of the side surfaces will be polished and left uncoated in order to minimize the emissivity of the areas under the blanket. We shall attempt to attain $\epsilon = 0.05$, or

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better. This finish will minimize the radiative interaction between adjacent packages. Moreover, this approach will minimize radiative leakage to the blanket and through any gaps to the spacecraft structure.

These combined approaches should stabilize the temperature of the package. We are planning to embed into the CEM three temperature sensors to determine the temperature fluctuation encountered during the mission at several crucial locations. The first sensor shall monitor the temperature of the interface to the thermal rail. A second sensor will be installed in close proximity to the stepping motor and the third close to the UV lamp.

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TIME (SEC)	ORBIT	ORBIT	IN	DELTA TEMP	OEM	TEMP	TEMP
540	.10	1	1	6.134E-02	300.61		
1140	.21	1	1	6.173E-02	301.23		
1740	.32	1	1	6.155E-02	301.85		
2340	.43	1	1	6.140E-02	302.46		
2940	.55	1	1	6.126E-02	303.08		
3540	.66	1	1	4.518E-01	303.40		
4140	.77	1	1	4.507E-01	303.43		
4740	.88	1	1	4.496E-01	303.42		
5340	.98	2	2	6.113E-02	311.60		
5940	.11	2	2	6.099E-02	304.21		
6540	.22	2	2	6.084E-02	304.82		
7140	.33	2	2	6.069E-02	305.42		
7740	.44	2	2	6.054E-02	306.03		
8340	.56	2	2	6.039E-02	306.63		
8940	.67	2	2	3.663E-03	306.90		
9540	.78	2	2	3.653E-03	306.93		
10140	.89	3	3	3.644E-03	306.97		
10740	.01	3	3	6.027E-02	307.12		
11340	.12	3	3	6.012E-02	307.72		
11940	.23	3	3	5.997E-02	308.32		
12540	.34	3	3	5.982E-02	308.92		
13140	.46	3	3	5.966E-02	309.52		
13740	.57	3	3	5.951E-02	310.11		
14340	.68	3	3	2.728E-03	310.31		
14940	.79	3	3	2.790E-03	310.34		
15540	.91	3	3	2.783E-03	310.37		
16140	.02	4	4	5.939E-02	310.57		
16740	.13	4	4	5.924E-02	311.16		
17340	.24	4	4	5.909E-02	311.75		
17940	.35	4	4	5.893E-02	312.34		
18540	.47	4	4	5.878E-02	312.93		
19140	.58	4	4	5.862E-02	313.52		
19740	.69	4	4	1.925E-03	313.65		
20340	.80	4	4	1.920E-03	313.67		
20940	.92	4	4	1.914E-03	313.69		
21540	.03	5	5	5.851E-02	313.91		
22140	.14	5	5	5.836E-02	314.52		
22740	.25	5	5	5.820E-02	315.10		
23340	.37	5	5	5.804E-02	315.68		
23940	.48	5	5	5.789E-02	316.26		
24540	.59	5	5	5.773E-02	316.84		
25140	.70	5	5	1.045E-01	316.91		
25740	.82	5	5	1.042E-01	316.92		
26340	.93	5	5	1.039E-01	316.93		
26940	.04	6	6	5.762E-02	317.22		
27540	.15	6	6	5.746E-02	317.80		
28140	.26	6	6	5.730E-02	318.37		
28740	.38	6	6	5.714E-02	318.94		
29340	.49	6	6	5.698E-02	319.51		
29940	.60	6	6	5.682E-02	320.08		
30540	.71	6	6	1.610E-04	320.00		
31140	.83	6	6	1.606E-04	320.09		
31740	.94	6	6	1.601E-04	320.00		
32340	.05	7	7	5.673E-02	320.43		
32940	.16	7	7	5.657E-02	320.99		
33540	.28	7	7	5.640E-02	321.56		
34140	.39	7	7	5.624E-02	322.12		
34740	.50	7	7	5.608E-02	322.67		
35340	.61	7	7	-7.288E-04	323.19		
35940	.73	7	7	-7.267E-04	323.18		
36540	.84	7	7	-7.246E-04	323.17		
37140	.95	7	7	-7.225E-04	323.17		
37740	.06	8	8	5.583E-02	323.55		
38340	.17	8	8	5.566E-02	324.11		
38940	.29	8	8	5.550E-02	324.67		
39540	.40	8	8	5.534E-02	325.22		
40140	.51	8	8	5.517E-02	325.77		
40740	.62	8	8	-1.621E-03	326.21		
41340	.74	8	8	-1.616E-03	326.20		
41940	.85	8	8	-1.611E-03	326.18		
42540	.96	8	8	-1.606E-03	326.16		
43140	.07	9	9	5.470E-02	326.60		
43740	.19	9	9	5.476E-02	327.15		
44340	.30	9	9	5.460E-02	327.70		
44940	.41	9	9	5.443E-02	328.24		
45540	.52	9	9	5.426E-02	328.78		
46140	.64	9	9	-2.511E-03	329.16		
46740	.75	9	9	-2.506E-03	329.13		
47340	.86	9	9	-2.499E-03	329.11		
47940	.97	9	9	-2.490E-03	329.08		
48540	.08	10	10	5.402E-02	329.57		
49140	.20	10	10	5.386E-02	330.10		
49740	.31	10	10	5.369E-02	330.64		
50340	.42	10	10	5.352E-02	331.10		
50940	.53	10	10	5.336E-02	331.71		
51540	.65	10	10	-3.405E-03	332.02		
52140	.76	10	10	-3.394E-03	331.90		
52740	.87	10	10	-3.383E-03	331.95		
53340	.98	10	10	-3.373E-03	331.92		

FIGURE 1

Computation of OEM Temperature Cycle Decoupled from Thermal Rail

Details:

Expanded Time Scale

Computational Increments 10 s

$\alpha = 0.9$

$\epsilon = 0.8$

$\beta = 30^\circ \rightarrow 60\%/40\%$

$T_o (OEM) = 300^\circ K = 27^\circ C$

ΔT is given for 10 sec

ORIGINAL PAGE IS
OF POOR QUALITY

ALPHA= .25 EPSILON= .9 INITIAL OEM TEMPERATURE= 300

TIME (SEC)	Z ORBIT	# ORBIT	DELTA TEMP	OEM TEMPERATURE
10	.00	1	3.146E-03	300.00
5350	.00	2	3.097E-03	301.12
10690	.00	3	3.049E-03	302.21
16030	.00	4	3.001E-03	303.27
21370	.00	5	2.954E-03	304.31
26710	.00	6	2.908E-03	305.32
32050	.00	7	2.862E-03	306.31
37390	.00	8	2.817E-03	307.27
42730	.00	9	2.773E-03	308.21
48070	.00	10	2.729E-03	309.13
53410	.00	11	2.687E-03	310.02
58750	.00	12	2.644E-03	310.90
64090	.00	13	2.603E-03	311.74
69430	.00	14	2.562E-03	312.57
74770	.00	15	2.523E-03	313.38
80110	.00	16	2.482E-03	314.16
85450	.00	17	2.445E-03	314.92
90790	.00	18	2.407E-03	315.67
96130	.00	19	2.371E-03	316.39
101470	.00	20	2.334E-03	317.10
106810	.00	21	2.299E-03	317.78
112150	.00	22	2.264E-03	318.45
117490	.00	23	2.230E-03	319.09
122830	.00	24	2.197E-03	319.72
128170	.00	25	2.165E-03	320.34

FIGURE 2

Computation of OEM Temperature Cycle Decoupled from Thermal Rail

Details:

Contracted Time Scale

Computational Increments 10 s

One Printout / Orbit

$\alpha = .25$

$\epsilon = .9$

$T_o (OEM) = 300^\circ K = 27^\circ C$

ΔT is given for 10 sec

ORIGINAL PAGE IS
OF POOR QUALITY

ALPHA= .9 EPSILON= .85 INITIAL OEM TEMPERATURE= 300

TIME (SEC)	% ORBIT	# ORBIT	DELTA TEMP	OEM TEMPERATURE
10	.00	1	1.014E-02	300.02
5350	.00	2	1.000E-02	303.41
10690	.00	3	9.361E-03	306.73
16030	.00	4	9.716E-03	309.87
21370	.00	5	9.570E-03	313.13
26710	.00	6	9.424E-03	316.21
32050	.00	7	9.277E-03	319.21
37390	.00	8	9.129E-03	322.14
42730	.00	9	8.982E-03	324.99
48070	.00	10	8.836E-03	327.75
53410	.00	11	8.689E-03	330.44
58750	.00	12	8.544E-03	333.05
64090	.00	13	8.400E-03	335.58
69430	.00	14	8.257E-03	338.04
74770	.00	15	8.115E-03	340.42
80110	.00	16	7.975E-03	342.72
85450	.00	17	7.837E-03	344.95
90790	.00	18	7.700E-03	347.10
96130	.00	19	7.566E-03	349.19
101470	.00	20	7.435E-03	351.20
106810	.00	21	7.305E-03	353.14
112150	.00	22	7.179E-03	355.01
117490	.00	23	7.054E-03	356.82
122830	.00	24	6.933E-03	358.56
128170	.00	25	6.814E-03	360.23

FIGURE 3

Computation of OEM Temperature Cycle Decoupled from Thermal Rail

Details:

Contracted Time Scale

Computational Increments 10 s

One Printout / Orbit

$\alpha = .9$

$\epsilon = .85$

$T_0 \text{ (OEM)} = 300^\circ\text{K} = 27^\circ\text{C}$

ΔT is given for 10 sec

ALPHA= .25 EPSILON= .9 INITIAL OEM TEMPERATURE= 300
 1 (12000 GRAHS) PACKAGES WITH 25 WATTS OF OUTPUT EACH

TIME (MIN)	% ORBIT	# ORBIT	DELTA TEMP	OEM TEMPERATURE
0.1	0.1	1	2.048E-03	300.00
39.1	0.1	2	2.033E-03	300.86
178.1	0.1	3	2.017E-03	301.71
267.1	0.1	4	2.001E-03	302.56
356.1	0.1	5	1.986E-03	303.39
445.1	0.1	6	1.970E-03	304.22
534.1	0.1	7	1.955E-03	305.04
623.1	0.1	8	1.939E-03	305.85
712.1	0.1	9	1.924E-03	306.66
801.1	0.1	10	1.908E-03	307.45
890.1	0.1	11	1.893E-03	308.24
979.1	0.1	12	1.877E-03	309.02
1068.1	0.1	13	1.862E-03	309.79
1157.1	0.1	14	1.847E-03	310.55
1246.1	0.1	15	1.832E-03	311.30
1335.1	0.1	16	1.816E-03	312.05
1424.1	0.1	17	1.801E-03	312.79
1513.1	0.1	18	1.786E-03	313.52
1602.1	0.1	19	1.771E-03	314.24
1691.1	0.1	20	1.756E-03	314.95
1780.1	0.1	21	1.742E-03	315.66
1869.1	0.1	22	1.727E-03	316.36
1958.1	0.1	23	1.712E-03	317.05
2047.1	0.1	24	1.697E-03	317.73
2136.1	0.1	25	1.683E-03	318.40

FIGURE 4

Computation of Temperature Cycle for OEM Coupled to Thermal Rail

Details:

Contracted Time Scale

Computational Increments 10 s

One Printout / Orbit

$\alpha = .25$

$\epsilon = .9$

$T_0 (OEM) = 300^\circ K = 27^\circ C$

ΔT is given for 10 sec

ORIGINAL PAGE IS
OF POOR QUALITY

ALPHA= .9 EPSILON= .85 INITIAL OEM TEMPERATURE= 300
 1 (12000 GRAMS) PACKAGES WITH 25 WATTS OF OUTPUT EACH

TIME (MIN)	Z ORBIT	# ORBIT	DELTA TEMP	OEM TEMPERATURE
0.1	0.1	1	4.956E-03	300.00
39.1	0.1	2	4.925E-03	301.32
178.1	0.1	3	4.893E-03	303.62
267.1	0.1	4	4.861E-03	305.40
356.1	0.1	5	4.829E-03	307.17
445.1	0.1	6	4.797E-03	308.92
534.1	0.1	7	4.764E-03	310.65
623.1	0.1	8	4.731E-03	312.36
712.1	0.1	9	4.698E-03	314.06
801.1	0.1	10	4.665E-03	315.74
890.1	0.1	11	4.632E-03	317.49
979.1	0.1	12	4.599E-03	319.04
1068.1	0.1	13	4.565E-03	320.66
1157.1	0.1	14	4.531E-03	322.27
1246.1	0.1	15	4.497E-03	323.86
1335.1	0.1	16	4.463E-03	325.43
1424.1	0.1	17	4.429E-03	326.99
1513.1	0.1	18	4.394E-03	328.51
1602.1	0.1	19	4.360E-03	330.03
1691.1	0.1	20	4.325E-03	331.52
1780.1	0.1	21	4.292E-03	333.00
1869.1	0.1	22	4.257E-03	334.46
1958.1	0.1	23	4.223E-03	335.90
2047.1	0.1	24	4.188E-03	337.33
2136.1	0.1	25	4.154E-03	338.73

FIGURE 5

Computation of Temperature Cycle for OEM Coupled to Thermal Rail

Details:

Contracted Time Scale

Computational Increments 10 s

One Printout / Orbit

$\alpha = .9$

$\epsilon = .85$

$T_o (OEM) = 300^\circ K = 27^\circ C$

ΔT is given for 10 sec

ALPHA= .6 EPSILON= .41 INITIAL OEM TEMPERATURE= 300
1 (12000 GRAMS) PACKAGES WITH 35 WATTS OF OUTPUT EACH

TIME (MIN)	2 ORBIT	3 ORBIT	DELTA TEMP	OEM TEMPERATURE
0.1	0.1	1	4.313E-03	300.00
99.1	0.1	2	4.239E-03	301.76
179.1	0.1	3	4.204E-03	303.50
267.1	0.1	4	4.203E-03	305.24
356.1	0.1	5	4.254E-03	306.97
445.1	0.1	6	4.238E-03	308.69
534.1	0.1	7	4.223E-03	310.40
623.1	0.1	8	4.207E-03	312.10
712.1	0.1	9	4.191E-03	313.80
801.1	0.1	10	4.175E-03	315.48
890.1	0.1	11	4.159E-03	317.16
979.1	0.1	12	4.143E-03	318.83
1068.1	0.1	13	4.126E-03	320.49
1157.1	0.1	14	4.109E-03	322.14
1246.1	0.1	15	4.092E-03	323.79
1335.1	0.1	16	4.075E-03	325.42
1424.1	0.1	17	4.058E-03	327.04
1513.1	0.1	18	4.041E-03	328.66
1602.1	0.1	19	4.023E-03	330.27
1691.1	0.1	20	4.005E-03	331.86
1780.1	0.1	21	3.987E-03	333.45
1869.1	0.1	22	3.969E-03	335.03
1958.1	0.1	23	3.951E-03	336.59
2047.1	0.1	24	3.933E-03	338.15
2136.1	0.1	25	3.915E-03	339.70

FIGURE 6

Computation of Temperature Cycle for OEM Coupled to Thermal Rail

Details:

Contracted Time Scale

Computational Increments 10 s

One Printout / Orbit

$\alpha = .6$

$\epsilon = .41$

T_0 (OEM) = 300°K = 27°C

ΔT is given for 10 sec

ORIGINAL PAGE IS
OF POOR QUALITY

/LINE= .35 EPSILON= 4.00000000E-02 INITIAL OEM TEMPERATURE= 300
 1 (12000 GRANT) PACKAGES WITH 25 WATTS OF OUTPUT EACH

TIME (MIN)	% ORBIT	" ORBIT	BELTA TEMP	OEM TEMPERATURE
0.1	0.1	1	3.762E-03	300.00
30.1	0.1	2	3.761E-03	301.79
170.1	0.1	3	3.779E-03	303.40
207.1	0.1	4	3.779E-03	305.10
256.1	0.1	5	3.777E-03	306.80
445.1	0.1	6	3.775E-03	308.50
534.1	0.1	7	3.774E-03	310.20
623.1	0.1	8	3.772E-03	311.89
712.1	0.1	9	3.771E-03	313.59
801.1	0.1	10	3.769E-03	315.28
890.1	0.1	11	3.767E-03	316.98
979.1	0.1	12	3.766E-03	318.67
1068.1	0.1	13	3.764E-03	320.36
1157.1	0.1	14	3.762E-03	322.05
1246.1	0.1	15	3.761E-03	323.74
1335.1	0.1	16	3.759E-03	325.43
1424.1	0.1	17	3.757E-03	327.12
1513.1	0.1	18	3.756E-03	328.81
1602.1	0.1	19	3.754E-03	330.49
1691.1	0.1	20	3.752E-03	332.18
1780.1	0.1	21	3.750E-03	333.86
1869.1	0.1	22	3.749E-03	335.55
1958.1	0.1	23	3.746E-03	337.23
2047.1	0.1	24	3.744E-03	338.91
2136.1	0.1	25	3.742E-03	340.59

FIGURE 7

Computation of Temperature Cycle for OEM Coupled to Thermal Rail

Details:

Contracted Time Scale

Computational Increments 10 s

One Printout / Orbit

$\alpha = .35$

$\epsilon = .04$

$T_0 (OEM) = 300^\circ K = 27^\circ C$

ΔT is given for 10 sec

ALPHA = .3 EPSILON = 3.00000000E-02 INITIAL OEM TEMPERATURE = 300
 1 (12000 GRADES) PACKAGES WITH 25 WATTS OF OUTPUT EACH

TIME (MIN)	% ORBIT	# ORBIT	DELTA TEMP	OEM TEMPERATURE
0.1	0.1	1	3.572E-03	300.00
89.1	0.1	2	3.573E-03	301.64
178.1	0.1	3	3.577E-03	303.28
267.1	0.1	4	3.576E-03	304.92
356.1	0.1	5	3.575E-03	306.55
445.1	0.1	6	3.574E-03	308.19
534.1	0.1	7	3.573E-03	309.82
623.1	0.1	8	3.572E-03	311.46
712.1	0.1	9	3.571E-03	313.09
801.1	0.1	10	3.570E-03	314.73
890.1	0.1	11	3.569E-03	316.36
979.1	0.1	12	3.568E-03	317.99
1068.1	0.1	13	3.566E-03	319.62
1157.1	0.1	14	3.565E-03	321.25
1246.1	0.1	15	3.564E-03	322.88
1335.1	0.1	16	3.563E-03	324.51
1424.1	0.1	17	3.562E-03	326.14
1513.1	0.1	18	3.560E-03	327.77
1602.1	0.1	19	3.559E-03	329.40
1691.1	0.1	20	3.558E-03	331.03
1780.1	0.1	21	3.556E-03	332.65
1869.1	0.1	22	3.555E-03	334.28
1958.1	0.1	23	3.554E-03	335.90
2047.1	0.1	24	3.552E-03	337.53
2136.1	0.1	25	3.551E-03	339.15

FIGURE 8

Computation of Temperature Cycle for OEM Coupled to Thermal Rail

Details: Contracted Time Scale
 Computational Increments 10 s
 One Printout / Orbit
 $\alpha = .3$
 $\epsilon = .03$
 $T_0 \text{ (OEM)} = 300^\circ\text{K} = 27^\circ\text{C}$
 ΔT is given for 10 sec

ORIGINAL PAGE IS
 OF POOR QUALITY

TIME	Foot	Trail	DT OEM	DT RAIL	Foot	Trail
10	45.4	0.0	1.01E-02	0.00E+00	100.02	300.06
1150	28.1	17.0	6.26E-03	6.26E-03	101.04	300.51
2880	28.0	17.0	6.26E-03	6.26E-03	101.08	301.37
4120	1.7	1.0	3.80E-04	3.80E-04	102.26	301.76
5150	31.6	16.1	7.07E-03	5.94E-03	102.32	301.02
6630	27.1	16.9	6.23E-03	6.23E-03	103.15	302.45
8020	27.4	16.8	6.21E-03	6.21E-03	103.99	303.40
9150	1.4	0.6	3.34E-04	1.24E-04	104.36	303.06
10000	30.4	16.0	7.01E-03	5.89E-03	104.42	303.91
12020	27.6	16.7	6.17E-03	6.17E-03	105.24	304.73
13000	27.5	16.7	6.15E-03	6.15E-03	106.07	305.56
14000	1.2	0.7	2.62E-04	2.60E-04	106.43	305.93
16030	31.1	15.9	6.96E-03	5.83E-03	106.48	305.97
17160	27.4	16.6	6.12E-03	6.12E-03	107.29	306.79
18790	27.3	16.5	6.10E-03	6.10E-03	108.11	307.61
20000	0.9	0.5	3.12E-04	2.12E-04	108.67	307.97
21000	10.9	15.7	6.80E-03	5.77E-03	109.51	308.00
22790	27.1	16.4	6.06E-03	6.06E-03	109.32	308.01
24040	27.0	16.4	6.04E-03	6.04E-03	110.13	309.62
25370	0.6	0.4	1.56E-04	1.56E-04	110.48	309.98
26710	30.6	15.5	6.85E-03	5.72E-03	110.51	310.01
28040	26.9	16.3	6.00E-03	6.00E-03	111.31	310.81
29380	26.8	16.2	5.98E-03	5.98E-03	112.12	311.61
30710	0.4	0.2	0.92E-05	9.92E-05	112.66	311.96
32050	20.4	15.3	6.73E-03	5.66E-03	112.69	311.99
33380	26.6	16.1	5.95E-03	5.95E-03	113.28	312.77
34720	26.5	16.1	5.92E-03	5.92E-03	114.08	313.57
36050	0.1	0.1	4.22E-05	4.22E-05	114.41	313.91
37390	30.1	15.2	6.73E-03	5.60E-03	114.43	313.92
38720	26.4	16.0	5.80E-03	5.80E-03	115.21	314.71
40060	26.3	15.9	5.87E-03	5.87E-03	116.00	315.50
41390	0.1	0.3	-2.38E-05	0.00E+00	116.32	315.83
42730	34.2	13.6	8.09E-03	5.01E-03	116.34	315.83
44060	24.1	15.8	5.83E-03	5.83E-03	117.12	316.61
45400	26.0	15.7	5.81E-03	5.81E-03	117.90	317.39
46730	-0.5	0.0	-1.15E-04	0.00E+00	118.21	317.72
48070	41.7	0.0	9.32E-03	0.00E+00	118.21	317.72
49400	25.9	15.7	5.78E-03	5.78E-03	118.99	318.48
50740	25.7	15.6	5.75E-03	5.75E-03	119.76	319.26
52070	-0.9	0.0	-2.07E-04	0.00E+00	120.07	319.58
53410	41.3	0.0	9.23E-03	0.00E+00	120.06	319.58
54740	25.6	15.5	5.72E-03	5.72E-03	120.83	320.33
56080	25.5	15.4	5.70E-03	5.70E-03	121.60	321.09
57410	-1.3	0.0	-2.99E-04	0.00E+00	121.89	321.41
58750	40.9	0.0	9.14E-03	0.00E+00	121.87	321.41
60080	25.3	15.3	5.66E-03	5.66E-03	122.65	322.14
61420	25.2	15.3	5.64E-03	5.64E-03	123.40	322.90
62750	-1.7	0.0	-3.81E-04	0.00E+00	123.68	323.21
64090	40.5	0.0	9.05E-03	0.00E+00	123.65	323.21
65420	25.1	15.2	5.60E-03	5.60E-03	124.43	323.92
66760	25.0	15.1	5.58E-03	5.58E-03	125.18	324.67
68090	-2.1	0.0	-4.03E-04	0.00E+00	125.45	324.98
69430	40.1	0.0	9.04E-03	0.00E+00	125.40	324.98
70760	24.8	15.0	5.55E-03	5.55E-03	126.18	325.67
72100	24.7	15.0	5.52E-03	5.52E-03	126.92	326.41
73430	-2.3	0.0	-5.75E-04	0.00E+00	127.18	326.72
74770	39.7	0.0	8.86E-03	0.00E+00	127.12	326.72
76100	24.6	14.9	5.49E-03	5.49E-03	127.90	327.30
77440	24.5	14.8	5.47E-03	5.47E-03	128.63	328.13
78770	-2.9	0.0	-6.67E-04	0.00E+00	128.88	328.43
80110	39.3	0.0	8.77E-03	0.00E+00	128.81	328.43
81440	24.1	14.7	5.43E-03	5.43E-03	129.59	329.08
82780	24.2	14.7	5.41E-03	5.41E-03	130.32	329.81
84110	-3.3	0.0	-7.53E-04	0.00E+00	130.56	330.11
85450	38.9	0.0	8.63E-03	0.00E+00	130.47	330.11
86780	26.1	14.6	5.39E-03	5.39E-03	131.25	330.74
88120	23.9	14.5	5.35E-03	5.35E-03	131.97	331.46
89450	-0.0	0.0	-0.50E-04	0.00E+00	132.20	331.76
90790	38.5	0.0	8.57E-03	0.00E+00	132.10	331.76
92120	23.8	14.4	5.32E-03	5.32E-03	132.88	332.37
93460	23.7	14.3	5.29E-03	5.29E-03	133.59	333.08
94790	-4.2	0.0	-9.40E-04	0.00E+00	133.81	333.38
96130	38.1	0.0	8.50E-03	0.00E+00	133.70	333.38
97460	23.6	14.2	5.26E-03	5.26E-03	134.48	334.07
98800	23.4	14.2	5.24E-03	5.24E-03	135.18	334.67
100130	-4.6	0.0	-1.03E-03	0.00E+00	135.39	335.07
101470	37.7	0.0	8.41E-03	0.00E+00	135.27	335.07
102800	23.0	14.1	5.21E-03	5.21E-03	136.04	335.54
104140	23.2	14.0	5.18E-03	5.18E-03	136.74	336.24
105470	-5.0	0.0	-1.12E-03	0.00E+00	136.94	336.53

FIGURE 9

Computation of OEM Temperature Cycle Decoupled from Thermal Rail

Details:

Coupling by Thermal Conductivity Term

Expanded Time Scale

Computational Increments 10 s

$$\alpha = 0.9$$

$$\epsilon = 0.8$$

$$\beta = 30^\circ \rightarrow 60\%/40\%$$

$$T_0 (\text{OEM}) = 300^\circ\text{K} = 27^\circ\text{C}$$

ΔT is given for 10 sec

ALPHA = 0 EPSILON = .85 INITIAL OEM TEMPERATURE = 300
 1 (12000 GRAMS) PACKAGES WITH 25 WATTS OF OUTPUT EACH

TIME (MIN)	% ORBIT	# ORBIT	DELTA TEMP	OEM TEMPERATURE
0.1	0.1	1	1.034E-03	300.00
32.1	0.1	2	1.025E-03	300.55
178.1	0.1	3	1.015E-03	301.09
267.1	0.1	4	1.006E-03	301.63
356.1	0.1	5	9.972E-04	302.17
445.1	0.1	6	9.879E-04	302.70
534.1	0.1	7	9.787E-04	303.22
623.1	0.1	8	9.695E-04	303.74
712.1	0.1	9	9.603E-04	304.26
801.1	0.1	10	9.512E-04	304.77
890.1	0.1	11	9.421E-04	305.27
979.1	0.1	12	9.330E-04	305.77
1068.1	0.1	13	9.240E-04	306.27
1157.1	0.1	14	9.151E-04	306.76
1246.1	0.1	15	9.062E-04	307.25
1335.1	0.1	16	8.973E-04	307.73
1424.1	0.1	17	8.885E-04	308.21
1513.1	0.1	18	8.797E-04	308.68
1602.1	0.1	19	8.709E-04	309.15
1691.1	0.1	20	8.622E-04	309.61
1780.1	0.1	21	8.536E-04	310.07
1869.1	0.1	22	8.450E-04	310.52
1958.1	0.1	23	8.365E-04	310.97
2047.1	0.1	24	8.280E-04	311.41
2136.1	0.1	25	8.196E-04	311.85

FIGURE 10

Computation of Temperature Cycle for OEM Coupled to Thermal Rail
 Without Solar Influx

Details:

Contracted Time Scale

Computational Increments 10 s

One Printout / Orbit

$\epsilon = .85$

$T_o \text{ (OEM)} = 300^\circ\text{K} = 27^\circ\text{C}$

ΔT is given for 10 sec

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ALPHA= 0 EPSILON= .41 INITIAL OEM TEMPERATURE= 300
 1 (12000 GRAMS) PACKAGES WITH 25 WATTS OF OUTPUT EACH

TIME (MIN)	% ORBIT	# ORBIT	DELTA TEMP	OEM TEMPERATURE
0.1	0.1	1	1.609E-03	300.00
30.1	0.1	2	1.601E-03	300.20
179.1	0.1	3	1.603E-03	301.00
267.1	0.1	4	1.670E-03	302.70
356.1	0.1	5	1.668E-03	303.60
445.1	0.1	6	1.661E-03	304.48
534.1	0.1	7	1.653E-03	305.37
623.1	0.1	8	1.645E-03	306.25
712.1	0.1	9	1.638E-03	307.13
801.1	0.1	10	1.630E-03	308.00
890.1	0.1	11	1.622E-03	308.87
979.1	0.1	12	1.614E-03	309.73
1068.1	0.1	13	1.606E-03	310.59
1157.1	0.1	14	1.598E-03	311.45
1246.1	0.1	15	1.591E-03	312.30
1335.1	0.1	16	1.583E-03	313.15
1424.1	0.1	17	1.575E-03	313.99
1513.1	0.1	18	1.567E-03	314.83
1602.1	0.1	19	1.559E-03	315.67
1691.1	0.1	20	1.551E-03	316.50
1780.1	0.1	21	1.543E-03	317.32
1869.1	0.1	22	1.535E-03	318.14
1958.1	0.1	23	1.527E-03	318.96
2047.1	0.1	24	1.518E-03	319.77
2136.1	0.1	25	1.510E-03	320.58

FIGURE 11

**Computation of Temperature Cycle for OEM Coupled to Thermal Rail
 Without Solar Influx**

Details:

Contracted Time Scale

Computational Increments 10 s

One Printout / Orbit

$\epsilon = .41$

$T_o (OEM) = 300^\circ K = 27^\circ C$

ΔT is given for 10 sec

ALPHA= 0 EPSILON= 4.00000000E-02 INITIAL OEM TEMPERATURE= 300
 1 (12000 GRAMS) PACKAGES WITH 25 WATTS OF OUTPUT EACH

TIME (MIN)	% ORBIT	# ORBIT	DELTA TEMP	OEM TEMPERATURE
0.1	0.1	1	2.2573E-03	300.00
39.1	0.1	2	2.2567E-03	301.20
178.1	0.1	3	2.2555E-03	302.41
267.1	0.1	4	2.2545E-03	303.61
356.1	0.1	5	2.2535E-03	304.82
445.1	0.1	6	2.2527E-03	306.02
534.1	0.1	7	2.2517E-03	307.22
623.1	0.1	8	2.2508E-03	308.43
712.1	0.1	9	2.2498E-03	309.63
801.1	0.1	10	2.2488E-03	310.83
890.1	0.1	11	2.2478E-03	312.03
979.1	0.1	12	2.2468E-03	313.23
1068.1	0.1	13	2.2458E-03	314.43
1157.1	0.1	14	2.2438E-03	315.63
1246.1	0.1	15	2.2428E-03	316.82
1335.1	0.1	16	2.2418E-03	318.02
1424.1	0.1	17	2.2408E-03	319.22
1513.1	0.1	18	2.2398E-03	320.41
1602.1	0.1	19	2.2388E-03	321.61
1691.1	0.1	20	2.2378E-03	322.80
1780.1	0.1	21	2.2358E-03	324.00
1869.1	0.1	22	2.2348E-03	325.19
1958.1	0.1	23	2.2338E-03	326.38
2047.1	0.1	24	2.2328E-03	327.58
2136.1	0.1	25	2.2308E-03	328.77

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FIGURE 12

**Computation of Temperature Cycle for OEM Coupled to Thermal Rail
Without Solar Influx**

Details:

Contracted Time Scale

Computational Increments 10 s

One Printout / Orbit

$\epsilon = 0.04$

T_o (OEM) = 300°K = 27°C

ΔT is given for 10 sec

ALPHA= 0 EPSILON= 3.00000000E-02 INITIAL OEM TEMPERATURE= 300
 1 (12000 GRAMS) PACKAGES WITH 25 WATTS OF OUTPUT EACH

TIME (MIN)	% ORBIT	# ORBIT	DELTA TIME	OEM TEMPERATURE
0.1	0.1	1	2.272E-03	300.00
89.1	0.1	2	2.271E-03	301.21
179.1	0.1	3	2.271E-03	302.43
267.1	0.1	4	2.270E-03	303.64
356.1	0.1	5	2.269E-03	304.85
445.1	0.1	6	2.268E-03	306.06
534.1	0.1	7	2.268E-03	307.27
623.1	0.1	8	2.267E-03	308.48
712.1	0.1	9	2.266E-03	309.70
801.1	0.1	10	2.265E-03	310.91
890.1	0.1	11	2.264E-03	312.12
979.1	0.1	12	2.264E-03	313.33
1068.1	0.1	13	2.263E-03	314.53
1157.1	0.1	14	2.262E-03	315.74
1246.1	0.1	15	2.261E-03	316.95
1335.1	0.1	16	2.260E-03	318.16
1424.1	0.1	17	2.259E-03	319.36
1513.1	0.1	18	2.258E-03	320.57
1602.1	0.1	19	2.258E-03	321.78
1691.1	0.1	20	2.257E-03	322.98
1780.1	0.1	21	2.256E-03	324.19
1869.1	0.1	22	2.255E-03	325.39
1958.1	0.1	23	2.254E-03	326.60
2047.1	0.1	24	2.253E-03	327.80
2136.1	0.1	25	2.252E-03	329.00

FIGURE 13

**Computation of Temperature Cycle for OEM Coupled to Thermal Rail
 Without Solar Influx**

Details:

Contracted Time Scale

Computational Increments 10 s

One Printout / Orbit

$\epsilon = 0.03$

T_0 (OEM) = 300°K = 27°C

ΔT is given for 10 sec

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STRESS AND VIBRATIONAL ANALYSIS OF OEM STRUCTURE

A) STRESS ENVIRONMENT

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A stress analysis has been carried out to determine the adequacy of the structural design of the package and the integrity of individual components and mounts.

The reference frame for the application of the inertial forces is translated from the LDEF Data Sheet. The longitudinal axis of the experimental tray is assumed to be parallel with the orbiter axis "X". The outward normal is aligned radially with the "Z" axis of the vehicle. The plane defined by the experimental tray ("L-M") is parallel to the X-Y plane of the vehicle with an offset in the Z-direction.

The dynamic environment is predicated mainly by the forces developed during the launch and return phases, for which the related accelerations are indicated in the respective coordinates.

We have now assumed that the orbiter "X" axis is aligned with the minor axis of the optical plate of the OEM. Thus, the X-axis can be assumed to intersect the sample wheel which is located in the X-Z plane. From this geometry we can infer the distribution of the forces and the stresses on the various components.

B) STRESSES ON OEM STRUCTURE

The launch environment generates a maximum acceleration of -3.3 g along the X-axis. In the two transverse directions, the maximum values of the acceleration are $Y = \pm 1.0\text{ g}$ and $Z = \pm 1.5\text{ g}$.

We are, therefore, mainly concerned with the stress effects in the X-Z plane which comprises the optical plate of the OEM.

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The OEM structure is designed to be anchored solidly to the thermal rail by means of six 1/4-20 stainless steel bolts. This attachment has two purposes: first, we achieve rigid coupling to the cage structure of the IECM and, second, we obtain a low thermal impedance to the base rail.

The stainless steel bolts allow a minimum permissible stress of 6,000 psi. The combined tensile stress level will be about 1,200 psi/inch-lb of torque. This will result in an axial load in excess of 100 lbs/screw, or 600 lbs for the total package. With a projected weight of 25 lbs, this allows a large safety factor for dynamic stress.

The next members in the OEM structure are two "L" sections which run along the sides of the baseplate (Y-axis). The legs of the "L" are 1.25" x 1.25" with a web thickness of 0.25". Six 3-32 stainless steel bolts are used to fasten the "L" sections to the baseplate. The holes in the baseplate are threaded, so that no countersinking is necessary. The tensile stress level for these screws will be 3600 psi/in. - lb of torque. We have examined the torsional deformation and shear stresses appearing at these "L" sections. This effect is due to the acceleration of -3.3 g along the X-axis which couples to the OEM frame. This effect is largely offset by the stiffness of the optical plate. Thus, the "L" are stressed at the holding screws. The line between the two legs of the "L" will not be machined to a sharp 90° corner, but to a finite radius of curvature to avoid stress risers at that point.

We have analyzed the effect of the acceleration in the plane and transverse to the optical plate. The loading is due to the attached motor. We find the stress level to be only 20 psi with projected plate deflection of only $2 \cdot 10^{-4}$ in.

Furthermore, we have analyzed the elastic stability of the optical plate when subjected to uniform shear around all edges. This shear could arise from the moment generated during acceleration. The mass centroid has been assumed at the motor. This

situation will shift only slightly as all the additional subsystems are located in the OEM. The calculated limit for this instability is at 39,000 psi, which is far in excess of any anticipated stress level.

We have also studied the possibility of a twisting moment of the plate under transverse force in the Y-direction. In this situation, the plate is rigidized by six 8-32 stainless steel screws and in addition by an aluminum sheet of 0.0625 in thickness which is fastened at several points to the plate. The two lateral plates act as stiffening membranes providing ample additional rigidity.

The last point considered concerning the OEM structure is the possibility of a bending moment under the action of the longitudinal acceleration. In order to avoid stressing only the basemount, it appears advantageous to provide a retaining bar at the top of the IECM frame against which to anchor. This feature will offer solid containment of the OEM package after installation in the tray.

These calculations indicate that the OEM structure is basically sound when exposed to the projected acceleration environment.

C) EFFECTS DUE TO VIBRATIONS

The stresses appearing in the OEM package due to ascent and reentry are relatively minor. However, the vibrational environment is both intense and troublesome. The vibrational spectral density plateaus at $0.07 \text{ g}^2/\text{Hz}$ from approximately 80 to 350 Hz. A spectral integration yields the counterpart effect of approximately 5 g with random orientation.

The major subcomponents of interest in this connection are the optical plate, the sample wheel with sample holders and the radiation source.

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We have first investigated the possible vibrations of the optical plate. The assumption of free cantilevering is introduced ad hoc just to test the stability. For the first bending mode, we obtain a frequency of 75 Hz which is near the peak of the vibrational spectrum. The first torsional mode ($m = 2$) is at 300 Hz, but the higher order modes occur at progressively higher frequency, and thus can be neglected. From this knowledge, we have increased the lateral stiffness of the optical plate by anchoring at sequentially uneven intervals.

The next item analyzed is the sample wheel. Here, all the natural frequencies appear at rather high frequencies, thus, no resonant coupling will occur to the vibrational spectrum. The computations also indicate that the lower order modes for the sample holders appear at frequencies around 2 kHz which eliminates almost all of the launch environment vibrational spectrum.

Concerning the radiation source, the calculations are rather complex due to the nature of the object. It appears far simpler to rigidize the source initially and to subject the structure to the vibrational tests.

There are a number of individual components, such as set screws, which may be affected by the vibrations. Clearly, all the screws will be fastened with Locktite, or with a similar bonding agent, during assembly of the unit.

Thus, also the effects of the vibrational environment can be counteracted by proper features of the structure.

D) STRESSES ON MISCELLANEOUS COMPONENTS

All of the components and subsystems of the OEM are exposed to the stress field outlined before. Calculations have been carried out to cover geometries and components which are amenable to treatment. Typical of this category is the stepping motor support mount and sample wheel drive system.

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We have attempted to provide a solid mounting pad for the motor with shaft support by means of two roller bearings. The natural frequencies of these components are maintained in the fall-off region of the vibrational spectrum, or beyond. In this fashion, we minimize resonant coupling effects.

We have applied this analytical procedure to all cases where it appeared fruitful and feasible.

The validity of the theoretical forecast shall be checked in a future series of vibrational tests.

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SUMMARY OF WEIGHT ANALYSIS FOR OEM FLIGHT SYSTEM

<u>SUBSYSTEM OR COMPONENT</u>	<u>WEIGHT</u>	<u>REMARKS</u>
OEM Enclosure	8500 gm	
ARC Lamp	20 gm	Including Leads
ARC Lamp Power Supply	775 gm	
ARC Lamp Ballast Resistor	30 gm	
Bulova Chopper	38 gm	
Transmission Photomultiplier	51 gm	Potted
Scattering Photomultiplier	51 gm	Potted
Transmission / Scattering Photomultiplier Power Supply	167 gm	Potted
Transmission and Reflection Photomultiplier Preamplifiers, Lock-in Amplifiers and Scaling Amplifiers: Includes PCB board, PCB connector, and all components.	200 gm	(Estimate)
Controller and Sequencer Electronics: Includes PCB board, PCB connector, and all components.	200 gm	(Estimate)
Stepper Motor (Hurst TS)	620 gm	
Multifunction PCB: Includes Stepper Motor Logic, three Temperature Bridges and Amplifiers, and the Power-On switch. Includes the PCB, the connector, and all components.	200 gm	(Estimate)

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SUMMARY OF WEIGHT ANALYSIS FOR OEM FLIGHT SYSTEM

(Continued)

<u>SUBSYSTEM OR COMPONENT</u>	<u>WEIGHT</u>	<u>REMARKS</u>
<u>+ 15 VDC Power Supply</u>	114 gm	Potted
Input / Output Connector for GSE Interface	70 gm	Does not include cable connector.
System Input / Output Connector for Analog and Digital Outputs	≈ 70 gm	(Estimate)
System Input / Output Cable Connector for Analog and Digital Outputs	≈ 100 gm	(Estimate)
Power Input Connector	≈ 50 gm	(Estimate)
Power Input Cable Connector	≈ 35 gm	(Estimate)
Miscellaneous:		
System Wiring	300 gm	(Estimate)
Electronic Mounting Hardware (Nuts, Bolts, Washers, Cable Clamps, and PCB Card Guides and Supports)	100 gm	(Estimate)
Potting Compound for PCB's	60 gm	(Estimate)

TOTAL ESTIMATED WEIGHT OEM: 11,810 gm
26 lb

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SUMMARY OF POWER INPUT AND HEAT ANALYSIS FOR OEM FLIGHT SYSTEM

<u>SUBSYSTEM AND COMPONENTS</u>	<u>POWER INPUT</u>	<u>POWER DISSIPATED</u>	<u>DC P. S.</u>
UV LAMP POWER SUPPLY AND LOAD	24 W	18.7 W	+28 V
UV Lamp		1.3 W	--
Lamp Ballast Resistor 160 kohm		4 W	--
RADIATION CHOPPER	0.5 W	0.5 W	+28 V
PHOTOMULTIPLIER POWER SUPPLY	1.6 W	1.6 W	+28 V
TRANSMISSION CHANNEL Preamplifier, Lock-In Amplifier, Scaling Amplifier		0.5 W	+15 V
SCATTERING CHANNEL Preamplifier, Lock-In Amplifier, Scaling Amplifier		0.5 W	+15 V
CONTROLLER AND SEQUENCER ELECTRONICS		0.3 W	+15 V
STEPPING MOTOR AND LIMITING RESISTORS	8 W	8 W	+28 V
STEPPING MOTOR LOGIC DRIVER	1.7 W	0.8 W 0.7 W	+15 V +28 V
± 15 VDC POWER SUPPLY	5 W	2.4 W	+28 V
POWER SWITCH (Controlled by Spacecraft)	0.4 W	0.4 W	+28 V
POSITION DETECTOR	0.8 W	0.8 W	+28 V
TEMPERATURE MONITORS (3)		0.5 W	+15 V

MAX. POWER DURING ON-CYCLE	≈ 41 W	≈ 41 W	
AVERAGE POWER FOR 66 SEC ON EVERY 495 SECONDS (See Power Profile Graph)	25.6 W	25 W	

FOLDOUT FRAME

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LAUNCH POWER ON

OEM POWER ON COMMAND

SAMPLE POSITION

UV LAMP P.S. & LOAD

BULOVA CHOPPER

POWER ON SWITCH

PHOTOMULTIPLIER P.S.

$\pm 15\text{VDC}$ P.S. & SYSTEM LOAD

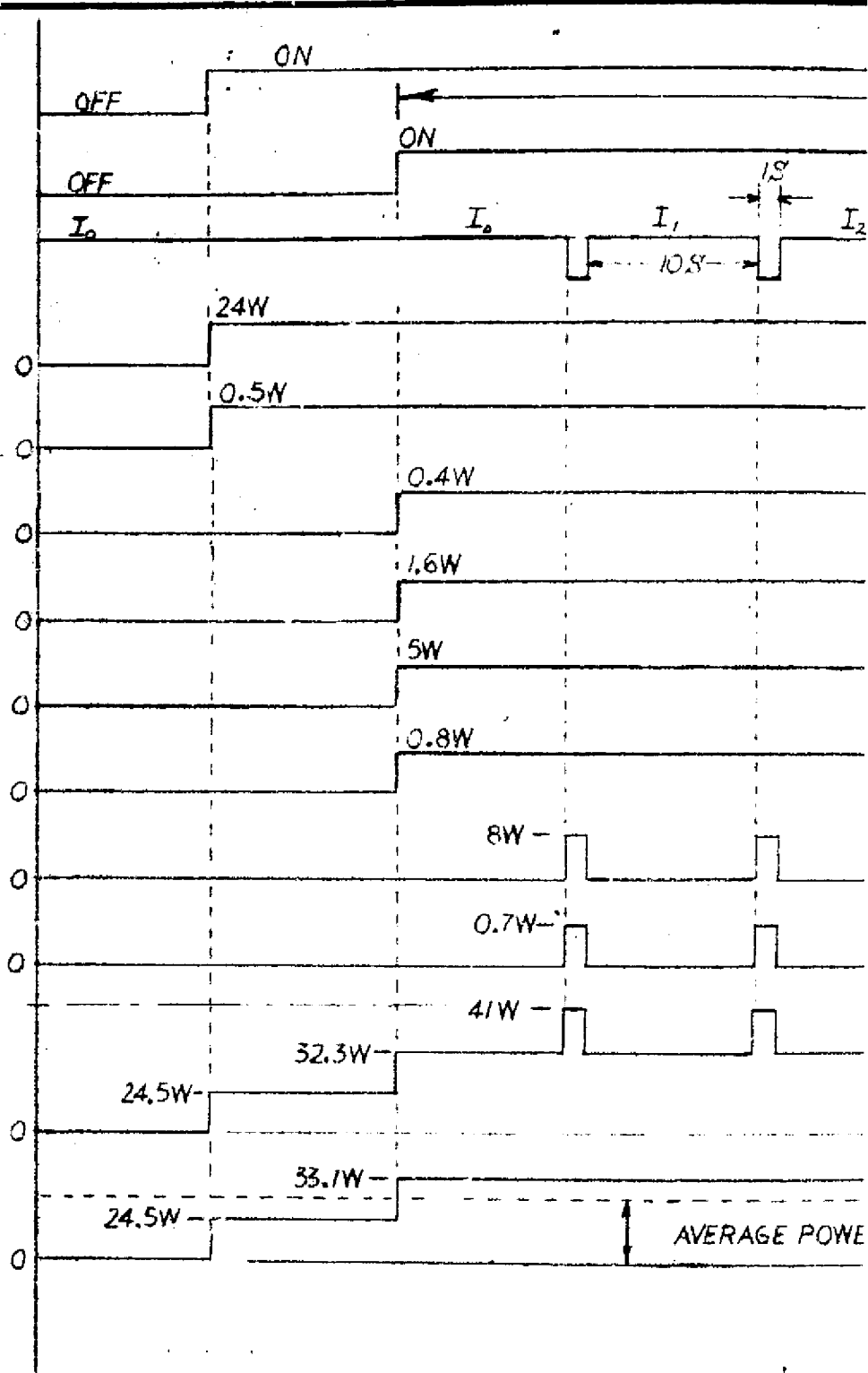
POSITION SENSORS

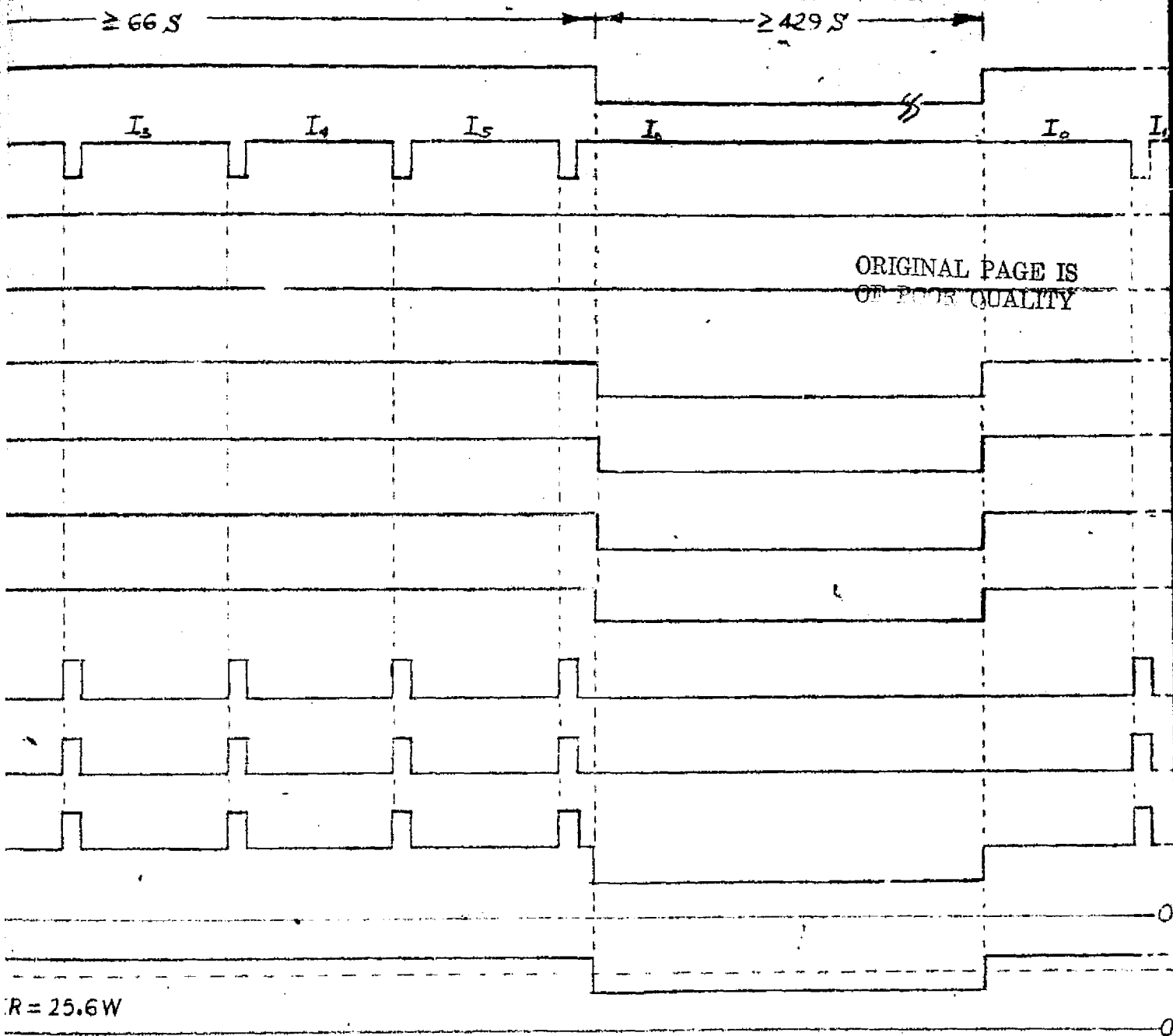
STEPPER MOTOR & PHASE
RESISTORS

STEPPER MOTOR LOGIC CKT
(+28V OUTPUT STAGE)

PEAK POWER PROFILE

AVERAGE POWER PROFILE &
AVERAGE POWER





ADVANCED KINETICS, INC. (714) 646-7165
1231 VICTORIA ST. COSTA MESA, CALIF. 92627

SCALE: ———

APPROVED BY: *Mollet*

DRAWN BY MOLLET

DATE: 5-19-77

PROJECT NO: 1054-404

REVISED

OEM POWER CYCLE PROFILE

DRAWING NUMBER

52

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OEM FLIGHT SYSTEM ELECTRONICS

A) INTRODUCTION

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The OEM Flight System Electronic Module is comprised of basically six subsystems:

- i) The Transmission and Reflection Signal Processing with Lock-in Amplifiers
- ii) Sample Wheel Sequencer and Controller
- iii) The Stepper Motor and Drive Electronics
- iv) The Chopper and Lamp Source
- v) The DC-DC Converter Power Supplies
- vi) The Temperature Bridges for OEM Diagnostics

Each of these subsystems will be discussed in detail in this chapter.

Two photomultiplier tubes are used to detect the transmission and reflection properties of the six sample positions (one being an open aperture). The multipliers are operated at different voltages, and the signals are processed via the lock-in amplifiers to provide a 0 to +5 VDC full scale output. This signal is correlated with the sample wheel position. In addition, a data ready level is provided to allow the analog output of the lock-in amplifier to be strobed into the spacecraft's processing network.

Position sensors will monitor the sample wheel to correlate the analog signal with the sample position. The position sensors will be interfaced with the sequencer-controller subsystem to correctly index and keep track of the sample wheel position. See Figure 1 for the basic flight block diagram.

The UV Lamp Power Supply represents the major portion of the allocated input power to the system. (See the Power Analysis section and the Power Profile Graph for details.) The UV lamp and its power supply characteristics have been carefully studied.

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The most reliable power supply, although inefficient, consists of an AC power supply with a series ballast resistor. An AC power supply is used to insure reasonable lamp lifetime. This supply has a peak open circuit voltage sufficient to ionize the UV lamp over the operating temperature range of 0°C to +70°C. The ballast resistor is gauged to limit the lamp current to 0.005 A.

The chopper will be a tuning fork type with an integral drive electronics. The chopper will not only modulate the lamp source, but will provide the reference signal for the lock-in amplifier. Since the chopper output signal is referenced to the +28 VDC power ground, an isolation transformer is used to decouple the signal and power grounds. The chopper frequency is 200 Hz with approximately 50% duty cycle.

The DC-DC converter will be of efficient design to provide the necessary power to the lock-in amplifiers, the controller-sequencer circuitry, the motor logic drive electronics, and the temperature bridges for OEM diagnostic studies. The power to these circuit subsystems is controlled by the spacecraft's Power On command signal. Refer to the Power Analysis section and the Power Profile Graph for more details.

The controller-sequencer electronics performs the logical sensing and positioning of the sample wheel assembly. It also provides the output data correlating the transmission and reflection signals with each sample position. The position outputs are TTL compatible with 1 unit load capability. The dwell or integration time for each sample is set by this circuitry as well as the index time to the next sample position. The signal integration time will be 10 seconds with an index time of 1 second. Thus, the total time to complete one complete revolution is 66 seconds. The spacecraft's Power On command should be greater than or equal to the 66 seconds minimum to complete one revolution so that the sample wheel that begins with the open aperture position (I_0) will also finish in the I_0 position. This sequence will insure that the sample wheel will be in the I_0 position at the start of each power-on cycle. If for some reason the " I_0 " is not in position at

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the start of the power-on cycle, the sample wheel will index to the I_0 position and stop to wait for the next power-on cycle. If the power-on cycle is too short, less than the 66 seconds, the next power-on cycle will not yield valid data since the I_0 reset will be Interrogated.

B) SPECIFICATIONS

Transmission Lock-in Amplifier Accuracy:	$\pm 0.5\%$
Reflection Lock-in Amplifier Accuracy:	$\pm 0.5\%$
Transmission Lock-in Amplifier Stability:	$\pm 0.5\%$
Reflection Lock-in Amplifier Stability:	$\pm 0.5\%$
Transmission Lock-in Amplifier Output:	0 to +5 VDC F.S.
Reflection Lock-in Amplifier Output:	0 to +5 VDC F.S.
Position Indicator Output:	BCD; 1-2-4-8, Positive True Parallel output TTL compatible (1 unit load)
System Sample (Integration) Time:	O: 10 s T: 10 s R: 10 s
Index Time (To new sample position):	1 s
Number of Sample Positions:	Six (6) 1 - Clear Aperture 5 - Reflective Position 5 - Transmissive Positions
Data Ready:	Positive true logic; TTL (1 unit load) compatible goes true when signal integration time is com- pleted. Pulse width ≥ 1 ms.
Chopping Frequency:	200 Hz
Chopping Frequency Stability:	100 ppm

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Power Input (Maximum Peak) : *	+23 VDC at 41 W
Power Input (Average) : *	+23 VDC at 25.6 W
Weight of OEM:	11.3 kg (26 lbs)
Dimensions of OEM:	43 cm x 28 cm x 28 cm (18 in x 11 in x 11 in)

* See the Power Analysis section and Power Profile Graph.

C) CIRCUIT DESCRIPTION AND DISCUSSION

1) Signal Processing

The signal processing consists of the following:

- i) UV Lamp and Power Supply
- ii) Chopper
- iii) Photomultipliers
- iv) Lock-in Amplifiers

a) UV Lamp and Power Supply

The UV Lamp and Power Supply is to be powered continuously to avoid unstable operation which would be encountered if it were to be cycled on and off by the IECM. The power supply represents the major power consumption of the OEM.

The UV Lamp Power Supply is a DC to AC inverter with a series current limiting resistor. This supply was found to be the most reliable over the operating temperature range of 0 to 70°C. This power supply, although inefficient, provides relatively constant current operation while allowing long life performance in the AC ignition mode.

The peak open circuit voltage is gauged to reliably ionize the lamp over the maximum operating extremes.

The DC-AC inverter is an Abbott Transistor Laboratories, Inc., Model SID-115A-1600. This inverter is rated for a +23 VDC input with an output of 115 VAC, 1600 Hz,

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at 10 VA. The output of the inverter drives the primary winding of a H.V. step-up transformer whose secondary open circuit voltage is sufficient to ionize the lamp at the operating temperature extremes. The secondary winding is connected to the series combination of the limiting resistor and the UV lamp. Below are listed some pertinent specifications of the lamp power supply system:

Inverter

Input Voltage Range:	+24 VDC to +30 VDC
Input Current:	0.79 A at 100% Load 0.71 A at 75% Load 0.59 A at 50% Load
Input Transient Protection:	In accordance with MIL-STD-704A, Figure 9, Limit 1 (80 VDC for 0.1 second)
Line Regulation:	+ 0.2% for 24 - 30 VDC input, with constant load.
Load Regulation:	+ 0.5% for load variations of 1/2 of full load, with constant line.
Waveform:	Sinusoidal, with maximum distortion into a resistive load of 2.5%.
Frequency Stability:	+ 0.5%
Load Power Factor:	Full rated output VA from unity to 0.7 PF lagging or leading.
Short Circuit Protection:	Protected against a short circuit condition of any duration.
Input Protection:	Reverse polarity protection.
Voltage Adjustment Range:	12% by screwdriver adjustment.
Temperature:	+100°C maximum at the mounting base plate using adequate heat sink. -54°C minimum at mounting base.

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Temperature Coefficient:

0.02% / °C from -20°C to +71°C
base temperature.

0.05% / °C over entire temperature
range.

Reliability:

This unit will meet or exceed most
of the environmental specifications
of MIL-STD-810C.

Incoming materials inspection per
MIL-STD-105C.

Approved in accordance with the
general reliability requirements of
MIL-I-45208A.

Failure Analysis in accordance with
MIL-HDBK-217.

Environment:

Encapsulated to meet the environ-
mental requirements of MIL-STD-
810C and MIL-E-5400², Class 2,
including altitude (to a vacuum),
vibration, shock, acceleration,
sand, dust, humidity, salt spray,
fungus, explosion, etc.

Isolation:

Inputs, outputs, and case are isolated.

WAD Transient Recovery Time:

Output voltage returns to regulation
limits within 5 cycles for a load
change of no load to full load.

Output Voltage:

100 - 122 VAC (rms)

Output Current:

120 mA Surge* Resistive Load
86 mA Continuous Resistive Load

*30 s at 21°C base plate temperature
2 s at 100°C base plate temperature

Weight:

0.77 kg (1.7 lb)

Transformer

Primary Voltage

115 VAC (rms); 1 ϕ , 1500 Hz

Secondary Voltage:

850 VAC (rms)

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Power:	5 VA
Specification:	In accordance with MIL-T-27C
<u>Limiting Resistor</u>	
Value:	160 K Ω
Power Dissipated:	4 W
Power Rating:	16 W
Manufacturer:	Allen Bradley
Part Type:	RCR42

b) Chopper

The chopper will consist of a Bulova tuning fork chopper with an integral driver. The power consumption is about 500 mW. The chopper also provides a 5 V p-p reference signal for the lock-in amplifier. This signal is common to the +28 VDC power ground, therefore, an isolation transformer has been used to isolate the signal and power grounds. The long-term stability is 100 ppm. The temperature coefficient is 50 ppm / °C. The chopper is to come on with the UV lamp to prevent errors due to the slow "build-up" time of the chopper.

Some more detailed chopper specifications are listed below:

Input Voltage:	+22 to +30 VDC
Input Power:	≤ 0.5 W
Chopping Frequency:	200 Hz
Frequency Accuracy:	$\pm 1\%$
Frequency " Build-up " Time:	≈ 20 s
Long-Term Stability:	100 ppm
Temperature Coefficient:	50 ppm / °C

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Operating Temperature:	-55°C to +85°C
Storage Temperature:	-65°C to +100°C
Altitude:	-1000 ft to outer space vacuum
Length of Aperture:	6 mm
Maximum Aperture Opening:	4 mm
Weight:	32 gm
Vibration:	To 20 G; Shock to 100 G
Radiation:	$>2 \cdot 10^{13}$ NVT

c) Photomultipliers and Power Supply

The photomultipliers will be mounted stationary within the sample wheel assembly so that they can observe the transmittance of the samples, the open aperture, and the reflective components. The photomultipliers (PMT) will be biased by an efficient H.V. switching regulator whose output is -1500 VDC for the reflection PMT and -1000 V for the transmission PMT. The output peak-to-peak ripple is less than 0.2% and a line regulation of 0.75% maximum for 25 V - 31 VDC input variation. Some further power specifications are given below:

Input Voltage:	+25 V to + 31 VDC
Input Power:	1.65 W Max (Depends upon load)
Output Voltage Range:	-875 V to -1750 VDC at 480 μ A
Output Voltage Programming:	Resistive (T.C. $\leq$ 500 ppm resistor)
Output Voltage Stability:	+ 1% for $V_i = 25$ VDC to 31 VDC; Temperature variations between -10°C to +65°C for an 8-hour elapse time.
Output Ripple:	2.5 V (p-p) max for $V_o = 875$ V and 480 μ A

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Grounding:	Input and output are isolated. H.V. output is wired for positive ground operation.
Operational Temperature:	-10°C to +65°C
Shock:	100 g for 11 ms
Vibration:	40 g; 20 to 3000 Hz
Altitude:	Unrestricted from sea level to outer space.
Non-operational Temperature:	-55°C to +125°C
Weight:	167 gm
Volume:	88.5 cm ³
Size:	5.74 cm x 5.66 cm x 2.95 cm (2.26" x 2.23" x 1.16")
Manufacturers:	EMR / Schumberger
Power Supply Model:	640E-i

Each PMT output is coupled via shielded leads to a low noise amplifier input stage.

The PMT signals are then processed by a dual lock-in amplifier system that provides a 0 to 5 VDC analog output signal.

d) Lock-in Amplifier

The dual lock-in amplifier will process the photomultiplier signals using the chopper signal as the reference for demodulation.

Low noise, low drift amplifiers are used throughout the design to provide stable performance over the operational temperature range of 0 to +70°C. Each amplifier has a separate phase adjustment to optimize the demodulation performance. The reference signal from the Bulova chopper is decoupled from the +28 VDC power ground via an isolation transformer. (Refer to Drawing #4.) The reference input is filtered and bandpassed to achieve a clean fundamental chopping frequency to be phase shifted. This processed

fundamental frequency is squared up via the high gain comparators whose outputs drive the demodulator FET switches in each lock-in amplifier section.

The output is scaled from 0 V to 5 VDC to correspond to zero input and to the maximum signal intensity expected, respectively. The outputs are averaged and buffered to provide a low output source impedance for the IECM signal processor.

The lock-in amplifier specifications are given below:

Accuracy:	$\pm 0.5\%$
Stability:	$\pm 0.5\%$
Output:	0 V to +5 VDC
Operating Temperature Range:	0°C to +70°C
Time Constant:	1.0 seconds
Phase Adjustment:	0 - 180°

e) Sequencer-Controller Electronics

The Sequencer-Controller performs all of the functions to properly correlate the sample wheel position and the signal being processed. The electronics for this function will be nearly all CMOS in design to conserve power.

The operation of the Sequencer-Controller electronics will now be discussed. (Refer to Drawing #2.) Two-position detectors (optical sensors) are used to detect the sample positions on the wheel. The open aperture (I_0) position is unique in that it has two small holes in the sample wheel to correspond its position. All the other positions ($I_1 - I_5$) have only one hole associated with their position. The circuit, as designed, will reset the sample wheel to the I_0 position if it should not be in that position initially when the spacecraft's Power On command signal is given. Since the Power On command has a fixed time cycle, tentatively set at a minimum of 66 s on (and 429 seconds off), the sample wheel must return to the I_0 position before the end of the power cycle to avoid a Reset command in the next power cycle. The output data will

not be valid in the Reset mode since the integration (dwell) time will be insufficient for accurate signal processing. The signals from the transmission and reflection PMT's will be valid and accurately correlated to the correct sample position when the sample wheel starts initially in the I_0 position. The position data output is updated by a counter and its output is buffered to drive two TTL loads. However, since the GSE interface requires a 1 unit load, the maximum loading allocated for the IECM will also be a 1 unit load when operating together.

An integrating time cycle will be initiated initially at the power-on cycle for a duration of 10 seconds. During this time the I_0 signal will be processed. At the end of the 10-second integration time, a Data Ready command will be generated to signal the IECM that the positional data and the transmission and reflection signal levels are valid. The Data Ready pulse width will be at least 1 ms wide. The Data Ready is TTL compatible with a 2 unit load capability. Like the position logic levels, 1 unit load is for the GSE and one for the IECM. The Data Ready pulse also initiates the command to step to the next position (I_1). The stepper motor power, as well as the index clock, is thus enabled to move the sample wheel. When the next sample position is sensed by the optical sensors, the stepper motor clock is stopped and the power is removed from the stepper motor itself to save power during the integration time. After the 10-second integration time, the Data Ready pulse is generated again to allow the valid data to be transferred to be processed. Again, a new index command is given to the stepper motor to move to the next position. This process is continued until the I_0 position is again reached. At this point the sample wheel will wait in the I_0 position even if the Power On command is substantially longer than the 66 seconds (minimum) allocated. The stepper motor will be off and the electronics will await the new Power On command before starting a new integration/index cycle over one complete revolution incorporating all six sample positions.

The motor clock is set at about 100 Hz to allow the motor to index to the new

position in 1 second. This will allow adequate speed-torque characteristic to reliably drive the sample wheel.

The GSE interface functions associated with the OEM operation will be discussed in the GSE Interface section.

f) Power Supply

The OEM requires +15 V, -15 V and the incoming +28 VDC for operation. The ± 15 VDC will be generated by a DC-DC converter. Both the ± 15 VDC outputs are capable of supplying the rated load current which has been minimized by the CMOS logic and low power amplifier designs.

The DC-DC converter specifications are as follows:

Input Voltage:	+28 VDC ± 3 VDC Continuous +50 VDC for 1 s Maximum
Output Voltage:	+15 VDC and -15 VDC (Nominal)
Output Current:	± 100 mA
Output Ripple:	90 mV (p-p); Maximum
Line Regulation ($V_i = 25 - 31$ VDC):	60 mV Typical 90 mV Maximum
Load Regulation (1/2 - Full Load):	350 mV Typical 410 mV Maximum
Temperature Regulation (-55°C to +100°C Case):	300 mV (Typical)
Protection:	Reverse polarity protected to 50 VDC
Input Current:	30 mA (Typ) for 100 mW Load 210 mA (Typ) for Full Load
Output Power:	3 W
Minimum Load:	100 mW
Output Voltage Adjust:	$\pm 10\%$ Full Load - 40% 1 Watt Load

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Isolation Test Conditions:	Input terminals shorted to case. Output terminals shorted together. 1000 VDC applied from output to case.
Polarity:	Inputs and outputs are floating from each other.
Operating Temperature Range:	-55°C ambient to +100°C case
Storage Temperature Range:	-55°C to +150°C
Case Rise:	25°C (Full Load)
Operating Frequency:	3 kHz $\pm$ 20%
Ripple Frequency:	3 kHz $\pm$ 20%
Weight:	114 gm fully encapsulated
Environment:	Designed to meet the requirements of MIL-E-5400
Manufacturer:	Technetics
Power Supply Model:	9567-121

A power switch is provided to interface with the control signal from the IECM. A +3.5 to +5 VDC level will turn this switch on, thus powering the OEM electronics, excepting the UV lamp and the Bulova chopper.

g) Temperature Monitors for System Diagnostics

Three linear temperature bridges are incorporated for system diagnostic purposes. (Refer to Drawing #3 for the details.) These three identical bridges incorporate a stable platinum sensor in one arm of a basic Wheatstone bridge. These sensors will be located near the UV lamp, the stepper motor, and a strategic point on the OEM housing. The temperature range will be from 0°C to +100°C. The bridge amplifier outputs will range from 0 V to +5 VDC corresponding to the 0°C and 100°C points, respectively. The output sensitivity will, therefore, be 50 mV/°C. The IECM may interrogate these outputs at the end of each power-on cycle to achieve some temperature profile of the OEM system and its components.

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DATA ANALYSIS

The data collected during every time cycle shall comprise the following parameters:

Transmitted Intensities:	$I_0, I_1, I_2, I_3, I_4, I_5$
Scattered Intensities:	$S_0, S_1, S_2, S_3, S_4, S_5$
Temperatures:	T_1, T_2, T_3

Here, I_0 and S_0 are the transmitted and scattered intensities for the empty position (sample holder in place without sample). The other parameters (I_n and S_n) denote the transmitted and scattered intensities with the five samples in place.

The processing of the data involves the following steps:

Normalization of Transmitted Intensities: $I_1/I_0, \dots, I_5/I_0$

Normalization of Scattered Intensities: $S_1/I_0, \dots, S_5/I_0$

Computation of Statistical Deviations by Subdivision of Data in Sample Populations as a Function of Exposure Time

Expansion in Time of the Sample Populations and Determination of Statistically Significant Deviations

Statistical Treatment and Correlation Testing of all Channels both in Transmission and in Reflection

In addition, the temperatures, as collected by the three household channels (baseplate, motor mount, light source housing) during each cycle, will be recorded and analyzed in combination with the data.

After recovery of the OEM, it is of basic importance to initiate a testing program of the samples without any additional contamination. Hence, the samples should be recovered and encapsulated in a clean laboratory. Subsequently, these samples should be analyzed for transmission and scattering at several wavelengths. Furthermore, the

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angular distribution of the scattered radiation should also be measured. These results, in combination with electron microprobe analysis, shall yield the thickness and size distribution of the contaminants as a function of time of exposure in orbit.

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TEST PROGRAM

A Flight Qualification Test Procedure (FQTP) shall be generated to test the OEM packages to the environmental conditions outlined in the MSFC specifications for the IECM document #61M10027. The FQTP shall be submitted to MSFC by the end of June, in line with the Time Schedule for the Program attached with this presentation.

The FQTP shall entail the following Test Program.

A) THERMAL ENVIRONMENT TESTS

We shall cycle the components of the OEM and the structure over the required non-operational temperature limits of -55°C to $+100^{\circ}\text{C}$. All the components shall be subjected to this cycle before incorporation into the related subsystems or PCB's. A determination will be made of the integrity of the component once the operational temperature limits are reestablished.

The second category includes thermal shocks between the required temperature extremes of -55°C and $+70^{\circ}\text{C}$. We would suggest to exclude from such tests the samples of MgF_2 , LiF and CaF_2 , since these crystalline lattices are susceptible to very abrupt (< 1 sec) thermal shocks. The temperature interval of 135°C could be incremented in several gradual steps on the time scale of seconds. This would correspond to the maximum dT/dt which could be encountered during a mission. All the other components shall undergo this specification.

The third category of tests shall cover thermal vacuum conditions. We shall test the OEM and its components for operation under vacuum conditions and under temperature excursion over the operating range $0^{\circ} - 70^{\circ}\text{C}$. We can control the vacuum pressure by means of diffusion pump and liquid nitrogen cooled baffle. However, we cannot provide a space chamber with LN interstitial cooling. This complete test will be carried out at

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the MSFC space chamber facility.

All the temperatures quoted here will be sensed by precision platinum thermometers calibrated at several basic points and computer-fitted by means of the Callendar-Van Dusen equation.

B) EMI COMPATIBILITY TESTS

We shall carry out tests with the OEM in full operation to determine full EMI compatibility with the IECM system. The guidelines shall be MIL STD 461A and 462.

These tests shall include detailed diagnostics in a screened room and with use of wideband CRO and sensors.

C) HUMIDITY TEST

A humidity cycling test will be included, in line with MIL STD 810 C. However, we would like to exempt the optical samples from exposure to extreme situations in moisture and temperature other than those which occur in a natural environment. The fluoride salts are slightly hygroscopic and some surface damage may result from protracted exposure to high moisture and high temperature conditions.

All other components shall be exposed to the standard moisture cycle.

D) CONTAMINANT OUTGASSING

Components and the OEM structure shall undergo vacuum testing over the operational temperature range. Change in pressure after blank-off of the diffusion pump shall be recorded at different intervals to infer the amount of outgassing.

Final outgassing tests shall be conducted with a quadrupole mass spectrometer at the MSFC facilities. The vacuum-tight feedthroughs for these tests shall be provided by ADKIN.

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Tests on the outgassing of three components of the OEM have been carried out in March at the MSFC facilities. The first test was conducted on the stepping motor on March 22, 1977.

Initial pressure was around $3 \cdot 10^{-6}$ Torr and this level was probably attributable to the outgassing due to manipulation of the object. The temperature of the stepping motor was raised initially to 43°C (110°F). The initial distribution of the effluents comprised at least some ten peaks ranging from approximately 28 to 111 AMU. Overnight pumpdown reduced the pressure level by more than an order of magnitude to 10^{-7} Torr. The motor temperature was increased to 52°C (125°F) which accelerated the final outgassing. After a few hours, the final pressure was down to 10^{-9} Torr with very few mass peaks remaining between 97 and 125 AMU. The background pressure of the space chamber with the motor removed was only slightly better at roughly 10^{-10} Torr with residual mass peaks at 97 to 119 AMU.

Thus, it appears that the stepping motor can be outgassed by conventional baking techniques and that the residual pressure is in the range of 10^{-9} Torr. This motor was lubricated with low vapor pressure Octoil S during fabrication. Hence, it appears that the motor can be operated in the component compartment without additional encapsulation.

The inverter power supply has been subjected to the same outgassing tests. The results appear to indicate that the same degree of pressure can be attained after an initial period of more copious outgassing.

E) VIBRATIONAL TESTS

The vibrational tests must be carried out by a testing laboratory equipped for these measurements. Thus, the OEM packages shall be transferred to a site where these tests can be conducted. The parameters outlined under paragraph 8 of the MSFC document shall be complied with.

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We suggest to exempt the OEM from the repeated drop test of 26 times from a height of 48 inches.

F) OTHER TESTS

The test program shall also concentrate on numerous tests related to the performance of the package in the orbital environment. We are particularly interested in following the performance of the instrument under variation of the operating temperature to investigate the possibility of drifts and to determine if the basic accuracy of each unit is unaffected.

Other tests include cyclic application of power and its effect on data accuracy.

SAFETY ANALYSIS

We have analyzed the OEM package from the viewpoint of safety and we have covered the following aspects:

a) Explosive Gases or Fumes

No gases are stored in the OEM package and no fumes can be generated over the contemplated operational temperature range of 0°C - 70°C.

b) Overheating of Components

We have provided a current limiting sensor with automatic shut-off of the circuitry to avoid any possible over-current mode. This sensor will be set for a reasonable maximum current selected to satisfy the power requirements during peak load cycle.

c) Disintegrating Fuses

We have eliminated completely the use of protective fuses to avoid the possibility of explosive disintegration.

d) Stalling of Motor

The stepping motor selected is designed to operate in a stalling mode indefinitely without overheating or extensive damage. This precaution has been incorporated to avoid the possibility of overheating in a high power component.

e) UV Lamp

A low pressure lamp has been selected instead of a high pressure type for generating the UV radiation. Thus, any breakage of the lamp would result in an implosion from sea level to an altitude of approximately 200,000 feet. The construction of this lamp is extremely solid with a double shell design of silica glass.

The lamp is completely contained in a surrounding aluminum housing. Hence, even in the unlikely event of breakage, no debris is allowed to disperse.

f) HV Breakdown

Two HV lines are used on the OEM. The first line connects the small power supply package to the two photomultipliers. We shall carefully dimension the insulation to avoid any corona or breakdown effects by

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a substantial margin. This operation entails a peak DC voltage of 1500 V with a current of 10 μ A.

The second line allows only transient application of a 1200 VAC (Peak) to initiate breakdown of the UV glow lamp. During operation, the lamp is running at 350 V crest. The remaining voltage is dropped across the ballast resistance.

We shall insulate very carefully this line and avoid completely unpotted transitions, sharp bends or other discontinuities which could induce local defects.

g) Elimination of PVC

All wires used in the OEM shall be of the Teflon coated type. No PVC is used in this package.

h) Selection of Sample Materials

All the selected sample materials are inert over the temperature range contemplated for operation. The materials are: crystalline quartz, sapphire, MgF_2 , LiF , CaF_2 . The last three samples have softening points between 400° and 600°C and should not be subjected to rapid thermal shocks. These two conditions are not encountered during the projected operation.

i) Thermal Safety

The package is designed in such a fashion that it will be thermally stable with the projected heat input of 25 W average power. The contact transitions and the radiative surfaces are engineered for efficient re-jection of the dissipated energy.

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SAMPLES ON SEQUENCER WHEEL

Five sample materials are preinstalled on the sample wheel (SW). In addition, there is one "Open" position. As seen from above the SW, the direction of rotation is counterclockwise. The samples are located in the following sequence:

Position	I ₀	Open Sample Holder
	I ₁	Sapphire
	I ₂	LiF
	I ₃	CaF ₂
	I ₄	MgF ₂
	I ₅	Crystalline Quartz

The samples are held in place by two thin Teflon O-rings compressed by the holding ring pressurized by four 4 - 40 flathead screws with Nylok inserts. For sample extraction or replacement, position the wheel by command to locate the sample outside the OEM chamber. Release carefully the screws around the ring and extract the sample without impairing its surface quality. Reverse this procedure for the installation of a new sample material. Tighten the four screws in a progressive sequence following a crosswise pattern.

REPLACEMENT OF UV LAMP

Replacement of the UV lamp requires disconnecting the line at the transition terminals to the step-up transformer. The transformer is potted together with the ballast resistors and including this transition point inside an aluminum can. This design is required to avoid breakdown in the vacuo of the high voltage line feeding the lamp.

The lid to the enclosure should be opened after removal of the four screws. The top layer of epoxy should be carefully removed. The connections of the lamp are to the case ground and to the two terminals (white and black wire). The wires to all three terminals should be unsoldered after the transitions are completely clear of the potting compound. The teflon sheathed line can then be removed carefully all the way to the OEM top compartment and to the lamp. The lamp is fastened by means of a 6-32 stainless steel Nylok screw.

A new lamp can be inserted in place and fastened in the same fashion. The power line is guided along the same route as before and the wires are soldered at the terminals. The potting compound is silicone 113-300 mixed with a TIPA catalyst in a 4:3 mixture. The compound will set at room temperature in 12 hours. Hardening can be accelerated by warming the volume with a gentle air flow at 40° C from a heated air gun.

After completion, the lid is fastened in place insuring that the compound has the consistency of an eraser.

CONCLUSIONS AND RECOMMENDATIONS

This Final Technical Report summarizes the engineering, manufacturing and testing activities carried out during a period spanning from September 1976 to June 1978. These activities resulted in the delivery of three space-worthy Optical Effects Modules to the NASA Marshall Space Flight Center for incorporation in the IECM system of the Space Shuttle.

The program lasted for a total period of 22 months. All activities have been on target timewise, exception made for the delivery by the manufacturer of the photomultipliers, an item which could not be obtained on schedule. The program entailed an initial Preliminary Design Phase of 4 months, a Critical Design Phase of 5 months and a remaining period of 13 months taken up by Manufacturing, Testing and Delivery of the three flightworthy packages of the OEM.

All the initially set target figures for volume and weight of the package and for power consumption have been fully satisfied. Performance has been secured not only for the transmission mode as originally specified, but also in a second channel in the reflection mode.

The design of the Optical Effects Module required solution of a substantial number of technological problems. In the forefront of our attention has been the source of radiation (UV lamp) whose performance under laboratory conditions was known only in a superficial manner. Considerable time had to be invested in devising the appropriate operating regime for this lamp to avoid the cataphoretic effects induced by the application of a DC electric field and resulting in reduced lifetimes. The high frequency operating mode developed for this operation has been beneficial with respect to lifetimes. It has also resulted

in appreciable savings of power by appropriate design of the inverter module and of the coupling transformer. Unfortunately, there was not sufficient time during this project to study the problems which are brought about by the extreme parameters of space operation. For instance, the change in the radiant output of the source with temperature has been apparent and it has been documented. The technique adopted in the measurements consists of taking ratios of the radiant absorption or scattering versus an empty sample position. Thus, to first approximation the effect of luminous radiance change is compensated. However, particularly at low temperatures, where condensation effects of the lamp dopant (mercury) take place, the luminous intensity decreases rapidly and ratios of small numbers become statistically less significant. At the other end, in the high temperature regime, the brightness increases rapidly with temperature imposing a demand for a wide dynamic range of the system, a feature which is not amenable to the limited acceptance of the recording system.

Initially, the system was based on the assumption of temperature stabilization to be provided by the IECM thermal rail. From the viewpoint of efficiency, thermal stabilization should have been the task of each individual package and it would have been a preferable choice also for the OEM. Thermal stabilization of the lamp at some intermediate temperature, e.g. $+30^{\circ}\text{C}$, would have entailed only a small power investment during cold orbits and a considerably reduced change in luminous intensity during the hot orbit cases. In effect, since this lamp may well be the only reasonable approach for the UV region for space applications, additional investigations should be devoted to develop temperature stabilized prototypes. With elevated constant temperature, the problem of dopant

absorption against the electrode surface (spongy molybdenum) may well be relieved, which would further improve the lifetime. Other types of electrodes (e.g. tungsten) should be studied to determine possible advantages in the glow discharge regime of operation.

Substantial problems were encountered in the area of the detectors (photomultipliers). The fact that only one single manufacturer exists now in the US for space-worthy photomultipliers with sensitivity in this particular region of the UV has been adversely felt during this program. The procurement cycle for the six photomultipliers required for the three OEM packages has lasted as long as the project itself , depriving us of the opportunity of examining these sensors more thoroughly before installation into the packages.

The complete circuitry for the OEM has been designed following the most advanced technology making use of low power CMOS devices. Selected devices of MIL specifications were difficult to obtain and the delivery cycle required generally 16 weeks or longer. In the planning for eventual refurbishment of photomultipliers and electronic components these extended delivery times should be taken into account.

In retrospect, the real difficulties encountered during the program may be ascribed to the acquisition cycle. It becomes progressively evident that industry at large is avoiding the manufacturing and testing obligations for selected small quantity components. Small business companies, such as BHK (UV lamps) and Hurst Manufacturing (stepping motors), have been a noticeable exception. These outfits have reacted with promptness to the special demands of the application.

A considerable amount of the program was taken up by paperwork. Some of these activities could possibly be reduced in the future at no detriment to the completeness of the project (e.g. 2 copies of the Monthly Technical Report instead of 15 copies). This could result in substantial savings to the NASA operation and to the contractor.

Finally, the constant liaison with the NASA Technical Monitor, Mr. Roger Linton, has proven to be the most useful element of the project. In all these high technology programs requiring performance within a very restricted time and budgetary framework, the need for close liaison between the agency and the contractor is of paramount importance in reaching optimal decisions rapidly. Periodic contacts with other members of the NASA IECM team have been very productive. This cooperative approach has made it possible to complete this program in a highly condensed schedule and in exceeding a number of the targets originally defined. The Optical Effects Module will serve as a real time contamination monitor on board of the Space Shuttle and should therefore become a useful instrument in future space programs.